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FINAL REPORT

REDUCTION IN FORAGE PRODUCTIVITY CAUSED BY CLUBMOSS

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Reduction in Forage Productivity Caused by Clubmoss

Funded by:

Saskatchewan Agriculture Development Fund

Project-9600054

Final Report

For the Period of

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Abstract

Clubmoss forms a ground cover on rangeland in the Brown and Dark Brown Soil Zones of southern Saskatchewan and Alberta. Many producers believe clubmoss inhibits growth and productivity of desirable plants by intercepting rainfall and competing for soil water. The objectives of the studies reported herein were to: determine if clubmoss intensifies drought and subsequently reduces forage productivity in Northern Mixed Prairie; determine clubmoss and precipitation affects on seedling emergence and survival; determine relationships between clubmoss cover, range condition, and seed reserves in the soil seedbank, and; complete an economic analysis of costs and benefits of mechanical treatment of rangeland to alter cover of clubmoss. Removing clubmoss from the sward did not increase or decrease soil water, reduce or improve plant water stress, improve productivity, and improve seedling emergence and establishment. Economic analyses indicate that chisel plowing is not economically feasible on any range site in the Brown and Dark Brown soil zones, and cost recovery of disking from 10 and 24 years. As a general rule environmental conditions, specifically the amount and timing of precipitation, likely outweigh any impacts that clubmoss may have on soil water, plant water stress, seedling emergence, and seedling survival. Therefore managers may want to maximize the functioning of the hydrologic cycle, the ability of plants to access water, and ensure that desired species are allowed to produce seed for regeneration. When these finding are considered together, it is concluded that range managers may find it useful focus their management efforts on issues other than clubmoss.

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Project Objectives

Low productivity of forages is a bottleneck in the production of beef that may be circumvented by improved management. Factors limiting forage productivity must, however, be isolated so proper management prescriptions can be made. As much as one may wish to increase beef production, the limits are ultimately determined by forage productivity. Producers must have information that allows them to make economically and economically prudent decisions. Information on the impacts of clubmoss on forage productivity is not, however, available. Clubmoss forms a common ground cover on large tracts of rangeland in Saskatchewan. Many producers believe clubmoss inhibits growth and productivity of desirable forages by intercepting rainfall and competing for soil water. By determining reductions in forage productivity caused by clubmoss, it will be possible to predict economic benefits of rangeland improvements to pastures with varying amounts of clubmoss. Results of this research will enable range managers to make economically and ecologically based management decisions that will allow maximum returns.

Canada's ratification of the United Nations Convention on Biological Diversity (Canadian Biodiversity Strategy 1995) is recognition of the need to maintain a healthy environment, prevent degradation of ecosystems, and loss of species and genetic diversity. Despite this commitment many practitioners of range management continue to recommend and employ practices that may threaten achievement of these goals. It is therefore imperative that biological relationships be elucidated to minimize or eliminate potential threats to biological diversity on rangelands before attempts are made to control clubmoss.

Objectives of this research were to:

- determine if clubmoss intensifies drought and subsequently reduces productivity in Northern mixed Prairie;
- determine effects of clubmoss on seedling establishment;
- determine seedbank content in rangeland with high cover of clubmoss, and;
- complete an economic analysis of costs and benefits of mechanical treatment of rangeland with clubmoss.

Contained within this report are four chapters describing the findings of each of these studies. Also contained in this volume is a summary chapter highlighting the salient findings and recommendations arising from these studies.

Literature Review

Northern Mixed Prairie, located in the northern portion of the Great Plains, is bound by Tallgrass Prairie to the southeast, Fescue Prairie to the north and northeast, and Fescue prairie in the Rocky Mountain foothills to the west. Climate is classified as cool and semiarid (Coupland 1950). Relatively low precipitation and extreme temperature fluctuations between summer and winter characterize Northern Mixed Prairie.

Surficial geologic deposits and soil parent material in Northern Mixed Prairie are mainly derived from glacial deposits (Christiansen 1979). Glacio-fluvial, lacustrine, and aeolian surface deposits are found less frequently throughout Northern Mixed Prairie. From these deposits two distinct soil zones have formed. A Dark Brown soil zone is located in the northern reaches of Northern Mixed Prairie and a Brown zone in the southern portion. The Dark Brown soil zone is characterized by cooler temperatures, higher precipitation, increased water use efficiency, and higher productivity, relative to the Brown soil zone (Coupland 1950). Soils in both soil zones have low organic matter content relative to soils of other grassland ecosystems (Coupland 1950). Low organic matter content is attributed to low resource availability and limited phytomass production. Primary factors limiting production in the Northern Mixed Prairie are water, nitrogen, and inappropriate management of rangeland resources.

Soil nitrogen is limited, ranging from 0.17 to 0.40 % in Dark Brown soil zone (Mitchell *et al.* 1944) and 0.14 to 0.24% in the Brown soil zone (Coupland 1950). In addition to limited soil nitrogen, low precipitation, high summer temperature, and warm, dry winds frequently limit soil water for plant growth (Coupland 1950). Mean annual precipitation ranges from 280 mm in the driest portions of the Brown soil zone to 450 mm in the Dark Brown soil zone (Coupland 1950).

Frequency and intensity of precipitation is spatially and temporally variable throughout Northern Mixed Prairie. Over a 12 year period, precipitation events of 2.5 mm or more occurred 31% of the time in Saskatchewan (Doughty *et al.* 1943 as interpreted by Coupland 1950). Throughout the Northern Mixed Prairie of Saskatchewan and Alberta 60 to 81% of precipitation received as daily events of 5 mm or less (J.T. Romo, unpublished data). Doughty *et al.* (1943) also noted precipitation events less than 7.5 mm did not increase soil water.

Plants in Northern Mixed Prairie have adapted to a climate dominated by light intensity rainfall events. Dense rooting in upper portion of the soil profile enable plants to capture moisture from small precipitation events. Of 6 North American grassland types, root production is greatest in Mixed Prairie, reaching a maximum of 2,500 g m^{-2} (Sims *et al.* 1978a). On average, 80% of total root biomass is in the top 30 cm of soil. In Saskatchewan, root biomass in the Dark Brown soil zone averaged 2,700 g m^{-2}, with about 60% of total occurring in the upper 30 cm of the soil profile (Coupland 1974).

Live shoot biomass in Mixed Prairie ranges from 101 to 270 g m^{-2} in Northern and Central Great Plains (Sims *et al.* 1978b). In Mixed Prairie of Canada, peak standing crop of green biomass ranges from 86 to 187 g m^{-2} (Coupland 1973). Peak standing crop is linearly related to precipitation received during growing season in areas of 100 to 450 mm annual precipitation (Sims *et al.* 1978b). Other factors such as sunlight, become more limiting than precipitation when annual precipitation exceeds 450 mm (Sims *et al.* 1978b). Current growing season precipitation, and annual usable incident solar radiation accounted for 75 and 64% of variability in total standing crop in ungrazed and grazed grassland, respectively (Sims *et al.* 1978a).

In semi-arid environments, water availability is one of the predominant factors affecting structure, function, and composition of plant communities (Willms and Jefferson 1993). Plant water relations are affected by distribution, movement, function, and status of water in soils, plants, and the atmosphere (Slatyer 1967, Kramer 1969). Water availability is affected by input characteristics such as frequency, intensity, and distribution of precipitation (Sala *et al.* 1982), and by site factors such as topography and soil properties (Barnes *et al.* 1982).

Throughout the Northern Mixed Prairie, a close relationship exists between timing and amount of precipitation and plant growth (Smoliak 1986). Precipitation from April through July is highly correlated with phytomass production (Smoliak 1986). Soil water during the previous fall and current season precipitation have the greatest effect on plant growth and yield in Northern Mixed Prairie (Rogler *et al.* 1947). In southwestern Saskatchewan and southeastern Alberta, available soil water and plant growth during May and June are closely related (Clarke *et al.* 1947). In July, declining growth of plants, coincides with depletion of soil water.

Plant growth in Northern Mixed Prairie typically begins in mid-April when soil water is readily available (de Jong 1973). Soil water reserves are recharged from snow melt in spring, and precipitation in May and June. Soil water reserves are generally least in August when plant and atmospheric demands are high (de Jong 1973).

Water availability is arguably one of the most important factors governing structure and function of Northern Mixed Prairie ecosystems (Redmann 1976). Amount, location, and duration of soil water are critical to spatial and temporal dynamics of ecosystem processes (Singh *et al.* 1998). Fluctuating climatic conditions change community structure, functioning, and composition on a continual basis (Clarke *et al.* 1943). In semi-arid environments, drought is the primary factor influencing vegetation change (Whitman *et al.* 1943). In Northern Mixed Prairie, cycles of drought and above-average precipitation affects yield, composition, and cover of plant communities. These community attributes vary throughout the Northern Mixed Prairie landscape in response to spatial and temporal variation of precipitation.

Timing is a key factor governing response of plants to precipitation. Phytomass production is one of the first plant processes to respond to lack of precipitation (Albertson *et al.* 1957). Current season precipitation has a great influence on phytomass production in Northern Mixed Prairie (Smoliak 1956), while moisture from snowfall, and the previous fall rain have less influence (Clarke *et al.* 1947).

Adding water in Northern Mixed Prairie increases phytomass production. In Montana, water spreading systems increased production up to 300% (Branson 1956), and adding twice the mean annual precipitation increased phytomass yield up to 200% in some areas (Klages and Ryerson 1965). In South Dakota, supplementing precipitation with water spreading increased yield by 16% (Cosper and Thomas 1961).

Although phytomass yield can be affected by one wet or one dry season, two or more wet or dry years are often required to change plant cover (Johnson 1981) and species composition (Coupland 1958). Prolonged drought during the 1930s reduced cover of grasses from 85 to 20% and drought in the 1950s reduced plant cover to 40%. Cover increased to pre drought levels following three years of above average precipitation (Albertson *et al.* 1957). During wet years, cover of litter also increased.

Native vegetation in Northern Mixed Prairie evolved under variable climatic conditions. Community composition changes in response to wet and dry periods, but native plants are seldom eliminated by variation of climate provided it is within the historical range (Olson *et al.* 1985). Following several wet seasons, species composition shifts to include greater cover of mesic species. By contrast, mesic species decline and xeric species increase during drought (Albertson *et al.* 1957). This response was observed by Coupland (1959) in Alberta and Saskatchewan. Species such as Junegrass, porcupine grass (*Stipa spartea* var. *curtiseta* (A.S. Hitchc.) Barkworth) and northern wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn.) increased following several wet seasons while blue grama and needle-and-thread decreased. Effects of drought on clubmoss cover are apparently undetermined at this time as conflicting responses have been reported (Clarke *et al.* 1942, Van Dyne and Vogel 1967).

Response of Northern Mixed Prairie to Mechanical Disturbance

Methods and effects of altering plant communities and their physical surroundings have been investigated throughout Northern Mixed Prairie. Procedures often involve mechanically disturbing grassland to alter soil and plant community characteristics. Mechanical disturbance changes structure, functioning, and composition of plant communities by altering resource availability and competitive interactions within the plant community (Wight and Siddoway 1972).

Mechanical disturbance alters soil water and nutrient availability and thus relationships among plants. Plant water status on mechanically disturbed areas is generally improved by increasing soil water availability throughout the growing season (Wight and Siddoway 1972, Neff and Wight 1977). Soil water increases on disturbed areas in response to decreased runoff, increased snow trapping, improved infiltration, and decreased transpiration from reduced plant cover. Effectiveness of treatment varies depending on site and vegetation characteristics (Griffith *et al.* 1985). On sandy sites, effects of mechanical disturbance are relatively limited because infiltration rates are naturally rapid and runoff is low (Branson *et al.* 1966). Plant community response following mechanical treatment of a sandy site is thus primarily due to increased availability of soil nutrients.

Mechanical disturbance of native grassland releases plant nutrients through soil weathering and decomposition of organic matter (Wight and White 1974), and stimulation of ammonifying and nitrifying microorganisms (McCalla 1967). Ryerson *et al.* (1968) observed effects of mechanical disturbance on nitrogen availability in native grassland by clipping vegetation at 7-cm intervals from treated areas. Plants 0-7 cm from the disturbance had greatest nitrogen content while plants further from the disturbance had less. Increased nitrogen content of plants was attributed to greater nitrogen availability caused by mechanical disturbance of soil.

Altering resource availability changes competitive relations within plant communities (Tillman 1985, Wilson and Tillman 1991). In native grassland, mechanical disturbance is applied to alter resource availability, thereby increasing phytomass production (Branson *et al.* 1966, Wight and White 1974, Griffith *et al.* 1985). Response of plant communities to disturbance is often variable and unpredictable (Westoby *et al.* 1989). Disturbance history, species composition, environmental variability, and site characteristics affect response of plant communities to mechanical disturbance. On silty loam soils, plant cover decreased by 50% and bare ground cover increased 6-fold following mechanical disturbance (Hart *et al.* 1985). One year following disturbance, litter cover increased, but vegetative cover remained limited relative to control. Change in structure was also reflected by phytomass yield. Production of agronomically desirable C_3 and C_4 species decreased relative to control following discing (Hart *et al.* 1985). Mechanical disturbance decreased abundance of dominant graminoids in the sward, and increased production of annual forbs.

On clay loam and sandy soil, disturbance similar to that applied by Hart *et al.* (1985) increased phytomass yield (Rauzi 1975). On the clayey site, yield of perennial grasses increased for four years following disturbance, and abundance of weedy forbs and annual graminoids remained low. On the sandy site, total herbage production averaged over five years was nearly double that of control with annual grass production increasing each year following disturbance. By the fifth year, dense stands of the annual cheatgrass (*Bromus tectorum* L.) accounted for 45% of total production while native dominants such as blue grama were reduced. These examples show how increased production in native grassland after mechanical disturbance can decrease range condition. Mechanical disturbance often promotes establishment of invading or early seral species (Rauzi 1975, Haferkamp *et al.* 1993) by creating resource gradients less favorable for late successional species. Establishment of early seral species have long-term consequences (Westoby *et al.* 1989), and may be counter productive to goals of rangeland management

Response of Northern Mixed Prairie to Nitrogen

Nitrogen fertilizer is often applied to increase forage production. Increased production after nitrogen fertilization has been observed throughout Northern Mixed Prairie (Kilcher *et al.* 1965, Smoliak 1965b), but response varies with climate, soils and management (Rauzi *et al.* 1968). Response of native rangeland to nitrogen fertilizer is affected by spatial and temporal variability of plant communities and climate. Communities dominated by C_3 or C_4 species have differential response to nitrogen (Williams 1953) depending on timing of application. Lorenz *et al.* (1972) concluded that nitrogen applied in late fall or spring benefited C_3 species more than C_4 species because the former initiate growth early in spring when cool soil temperatures inhibit microbial activity and nitrification. Applied nitrogen is therefore available to C_3 species before C_4 species have initiated growth. Added nitrogen causes earlier and more rapid growth in early spring (Rogler *et al.* 1957), which may alter competitive relations between C_3 and C_4 species (Rogler *et al.* 1957,). C_3 species also complete more growth earlier in spring. This early growth enables C_3 plants to take advantage of abundant soil water, reducing resource availability for later developing C_4 species. In some situations, C_3 species such as Junegrass and needle-and-thread decline when nitrogen is added (Johnston *et al.* 1967). These species were replaced by western wheatgrass (*Agropyron smithii* Rydb.), northern wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn.), pasture sage (*Artemisia frigida*

Willd.), foxtail barley (*Hordeum jubatum* L.), and various forbs (Johnston *et al.* 1967). No C_4 species increased after nitrogen application, and many species invading the sward were unpalatable forbs and half-shrubs.

In Northern Mixed Prairie, response of species composition and yield to nitrogen is related to amount and timing of precipitation (Klages *et al.* 1965, Lorenz and Rogler 1972). Species composition remained constant following nitrogen application until years with below average precipitation were experienced (Klages *et al.* 1965). Following two years of drought, grass yield decreased significantly and residual effects of nitrogen fertilization were reflected in stimulated growth of early seral species (Klages *et al.* 1965). These compositional changes have potential to alter soil and plant water relations.

Nitrogen fertilizer can increase water use efficiency of plants (Wight *et al.* 1979), soil water extraction, evapotranspiration (Wight *et al.* 1978), yield, and plant vigor (Johnston *et al.* 1969). Nitrogen promotes root growth (Haase 1958, Lorenz *et al.* 1967, Goetz 1969), enabling greater extraction of soil water (Smika *et al.* 1961). This increased soil water extraction decreases soil water more than if nitrogen is not added, thereby possibly reducing yield in following years (Rogler *et al.* 1957). Adding nitrogen intensified drought over two consecutive years leading to reduced densities of blue grama (Hyder *et al.* 1976).

Adding nitrogen to native grassland can decrease phytomass yield by altering species composition (Lorenz *et al.* 1972). Annual application of high rates of nitrogen reduced dry matter production and caused rapid changes in community composition such as replacement of blue grama with western wheatgrass (Lorenz *et al.* 1972).

Effects of Clubmoss and Precipitation on Soil Water, Plant Water Status, and Plant Production in Northern Mixed Prairie

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Abstract

Clubmoss (Selaginella densa) forms a common ground cover on native rangeland in Saskatchewan and is often regarded as a factor limiting plant productivity. The belief that clubmoss inhibits growth of desirable plants by intercepting rainfall and competing for soil water has led many rangeland managers to apply costly, and possibly unnecessary, disturbances to reduce clubmoss. Sward disturbances (mechanical, nitrogen added, glyphosate to kill clubmoss, raking to remove clubmoss, and an undisturbed control), and precipitation treatments (irrigation, ambient precipitation reduced, and control—natural precipitation) were applied to determine if clubmoss affects soil water and leaf xylem water potentials in Junegrass (Koeleria cristata (L.) Pers.) and blue grama (Bouteloua gracilis (H.B.K.) Lag) and peak standing crop of graminoids in Northern Mixed Prairie. A second study was also conducted to determine the effects of clubmoss and simulated precipitation ranging from 0 to 25 mm on soil water and leaf xylem water potentials of Junegrass and blue grama. Soil water and leaf xylem water potentials generally declined through the summer and usually did not respond to sward disturbances ($P \geq 0.05$). Precipitation treatments had a more consistent effect on soil and leaf xylem water potentials of Junegrass and blue grama than did sward disturbances. On dates where differences existed among precipitation treatments ($P \leq 0.05$), irrigating increased soil water 0.3 to 3.7% relative to control, reducing precipitation decreased soil water 0.4 to 5.2% relative to control, and irrigating increased soil water 0.5 to 8.4% compared to reducing precipitation. Irrigating did not usually affect leaf xylem water potentials of Junegrass and blue grama relative to control ($P \geq 0.05$), but reducing precipitation decreased leaf xylem water potentials between 0.2 and 3.1 MPa and 0.2 and 3.4 MPa compared to control and irrigation, respectively. Response of graminoids to sward disturbances was inconsistent, but their production increased ($P \leq 0.05$) 25 to 36 g m^{-2} when irrigated relative to reducing precipitation. Response of biomass production to sward disturbances and precipitation treatments was also variable or no differences were observed ($P \geq 0.05$). When 0 to 25 mm of water was added as simulated precipitation events, clubmoss generally had no effect ($P \geq 0.05$) on soil water and leaf xylem water potentials of Junegrass and blue grama. These studies indicate that clubmoss does not reduce soil water, increase plant water stress, or reduce productivity. Instead, results indicate that the amount of precipitation has far greater impacts on soil water and plant water stress and productivity than clubmoss.

Introduction

Clubmoss (*Selaginella densa* Rydb.), a low growing, non-flowering, vascular plant grows in dense mats on the soil surface in Northern Mixed Prairie. Cover estimates of clubmoss in Northern Mixed Prairie range from 28 (Heady 1952) to 80% (Dolan and Taylor 1972). Roots of clubmoss form an extensive mass of minute branches 2 to 5 cm below the soil surface (Coupland and Johnson 1964).

Extensive cover and the dense rooting of clubmoss have led some rangeland managers to assume that this plant negatively effects soil and plant water relations, particularly during drought and in environments dominated by small precipitation events (Dolan 1966, Wagner 1966, Taylor 1967). Apparently no controlled experiments have been conducted to characterize the effect of clubmoss on water relations in the semiarid environment of Northern Mixed Prairie.

Timing and amount of precipitation are primary factors limiting phytomass production in Northern Mixed Prairie (Albertson 1957, Smoliak 1956). May and June precipitation is correlated with annual phytomass production, with May plus June precipitation being more closely related to production than any other factor (Smoliak 1956). Soil water in the previous fall along with soil water recharge over winter have also been identified as important factors influencing phytomass production in Northern Mixed Prairie (Neff 1980). Response of plant communities to precipitation varies with species composition (Olson 1985). Communities dominated by C_3 plants are most common in Northern Mixed Prairie. Most C_3 plants begin growing in early spring when the probability of receiving adequate moisture is highest and temperatures are cool (Pearcy *et al.* 1981). Under some situations, C_4 species may become locally dominant, thereby altering community response to seasonal precipitation.

Each species in a plant community responds differently to timing and amount of precipitation. Relative proportions of plant species are influenced most by climate, topography, soils, disturbance, biotic organisms, and management. Effects of each of these components on the soil-plant-atmosphere continuum vary in time and space. Despite this variability, some range managers have concluded clubmoss has significant influences on soil and plant water relations on Northern Mixed Prairie, and efforts should be directed to reducing the cover of this depauperate plant. Majarowicz (1963) concluded clubmoss competes with grass for moisture by acting as a sponge and absorbing water; water absorbed by clubmoss evaporates, becoming unavailable to plants.

A close relationship exists between growing season precipitation, evaporation, and phytomass production in Northern Mixed Prairie (Clarke *et al.* 1947). Clubmoss may play important roles in functioning of the soil-plant-atmosphere continuum by increasing or decreasing the precipitation/evaporation ratio. Improving water infiltration, reducing runoff, and decreasing soil temperature are ways clubmoss potentially increases the precipitation/evaporation ratio, thereby improving plant water availability (Van Dyne *et al.* 1967, Dolan and Taylor 1972).

Ground cover plays important roles in soil water relations on Northern Mixed Prairie (Rauzi 1960). Litter or mulch aids in conserving soil water by reducing soil temperature and evaporation (Weaver and Rowland 1952, Hopkins 1954). Clubmoss may play a role similar to litter in areas where phytomass production is reduced because of limited water, or where large amounts of biomass and litter are frequently removed. Research on ecological roles of clubmoss and how it affects soil and plant water relations has apparently not been conducted.

Attempts have been made to explain the ecological role of clubmoss in grasslands, but supporting evidence is often lacking. Clubmoss can survive low resource availability over a wide range of sites (Van Dyne *et al.* 1967). Low water requirements enable clubmoss to grow in areas with insufficient resources for sustaining extensive cover of forbs and graminoids (Webster *et al.* 1964). The ability of clubmoss to colonize disturbed areas with limited cover and resources has led some researchers to conclude clubmoss acts as a soil stabilizer (Van Dyne *et al.* 1967). Collectively, the low growth form, extensive ground cover, and dense rooting may allow clubmoss to play important ecological roles by providing cover in environments with unreliable resources and frequent disturbance.

Clubmoss tends to increase under grazing (Campbell *et al.* 1962, Smoliak 1965a, Abouguendia 1990) and during drought (Clarke *et al.* 1943). Clubmoss commonly grows where plant communities are disturbed by excessive grazing, and in areas affected by severe drought (Heady 1952). Others concluded clubmoss decreases under grazing because of trampling damage by livestock, and it increases under protection from grazing (Coupland 1950, Budd 1957).

Contrasting opinions on the function of clubmoss and community response to disturbance exemplifies complexity of ecological systems. Despite the absence of research on ecological roles of clubmoss, some scientists have studied several methods of decreasing its cover in attempts to improve production on native rangeland. Mechanical and chemical disturbances have been applied to rangeland to decrease cover of clubmoss and increase phytomass yield (Dolan 1966, Wagner 1966, Taylor 1967, Ryerson *et al.* No date). These researchers concluded that decreasing clubmoss by mechanical or chemical disturbances improved rangeland productivity, however, cause-effect relationships of clubmoss treatment and response were not determined.

Understanding the interdependent nature of plant communities within landscapes is key to making sound management decisions. In Northern Mixed Prairie, many range managers mechanically disturb native grassland to decrease clubmoss cover and increase phytomass production. Mechanical disturbance stimulates activity of soil microbes, increasing nitrogen availability (McCalla 1967). This additional nitrogen often increases production following mechanical disturbance (Griffith *et al.* 1985), and is not necessarily caused by decreased clubmoss as some researchers have concluded (Dolan 1966, Wagner 1966, and Taylor 1967). Increased phytomass production following mechanical disturbance is temporary and cost of disturbance often outweighs economic benefits (Peng *et al.* 1999). Mechanical disturbance modifies the site and alters resource gradients, often favoring early successional species (Griffith *et al.* 1985). Establishment of early successional species may create additional management issues.

Without knowledge of ecological functioning of clubmoss, applying mechanical disturbances to decrease its cover may be unnecessary and counter productive to overall management objectives. It is therefore necessary to determine if reducing the cover of clubmoss on native rangeland actually improves water relations and increases phytomass production.

The objective of the studies reported in this chapter was to determine if clubmoss influences soil and plant water relations, phytomass production, canopy cover, and phenological development of grasses. Studies were designed to compare:

- the effects of increasing or reducing precipitation relative to ambient precipitation;
- removing clubmoss from the sward relative to clubmoss present;
- killing clubmoss relative to live clubmoss in the sward;
- killing clubmoss relative to removing clubmoss from the sward;
- mechanically disturbing the sward relative to adding inorganic nitrogen to the sward; and;
- effects of clubmoss on soil water and plant water relations under conditions of simulated precipitation events ranging from 0 to 25 mm of water.

Materials and Methods

Research was conducted at two sites 60 km south of Saskatoon, Saskatchewan in the Dundurn Sandhills (51°31'N, 106° 48'W, 525 m elevation) in the summers of 1997 and 1998. These sites, Dundurn and Rudy, are classified as sandy range sites (Abouguendia 1990) with Dark Brown Chernozemic soils belonging to the Asquith association (Ellis *et al.* 1970). This soil developed on sandy, glacio-fluvial and lacustrine deposits, and is moderately coarse-textured. The Dundurn Sandhills formed along the south shore of glacial lake Saskatchewan 11,000 to 14,000 years ago (Christiansen 1979).

Stabilized sand dunes form the topographic structure of this area. Undulating topography influences spatial distribution of individual species throughout dunes. Different plant communities exist in sequence from tops of dunes, through the slope, into depressions and flat areas between dunes (Hulett *et al.* 1966). The primary grassland community is the sand dune complex of the Mixed Prairie formation (Hulett *et al.* 1966).

Structure and composition of vegetation in the dune complex varies spatially in response to physiographic position (Hulett *et al.* 1966). Stabilized dunes and sand flats make up the majority of area in the Dundurn Sandhills. Study sites at Dundurn and Rudy were located on sand flats. These areas are dominated by needle-and-thread, western porcupine grass, blue grama, and Junegrass. Common forbs and graminoids include pasture sage (*Artemisia frigida* Willd.), late yellow locoweed (*Oxytropis campestris* L.), hairy golden-aster (*Chrysopsis villosa* (Pursh) Nutt.), low goldenrod (*Solidago missouriensis* Nutt.), purple prairie clover (*Petalostemon purpureum* Vent), moss phlox (*Phlox hoodii* Richardson), Missouri milk-vetch (*Astragalus missouriensis* Nutt.), scarlet mallow (*Malvastrum coccineum* (Pursh) Gray), and low sedge (*Carex stenophylla* Wahl.)

Canopy cover of plants was similar at Dundurn and Rudy (Table 1). Total canopy cover averaged 33%. Total cover of graminoids averaged 24%, of which Junegrass and blue grama averaged 7 and 6 %, respectively. Total forb cover averaged 5%, while clubmoss provided 35% ground cover.

Annual precipitation averages 315 mm, with about 65% received from late April through September (Environment Canada 1982). During this period, most precipitation is received in May and June, and the least is received in July and August. In September 1996 through August 1997, 325 mm of precipitation were received which included 162 mm in September through March, 123 mm in April through June and 40 mm in July through August (Table 2). In 1997-98, total precipitation received before October was 282 mm, including 56 mm in September through March, 123 mm in April through June, and 95 mm in July through August (Table 2). Temperatures in this area range from an average of -17°C in January to 19°C in July (Environment Canada 1982). The first month of the year with mean monthly temperature above 0°C was April in 1997 and 1998 (Table 2). July and August were the warmest months in 1997 and 1998 (Table 2.

Research for this project was divided into two independent studies. The sward disturbance study evaluated effects of five sward disturbances combined with three water regimes on soil and plant water relations, phytomass production, canopy cover, and phenological development of grasses. The second study tested the influences of simulated precipitation and clubmoss on soil and plant water relations.

phenological development of grasses. The second study tested the influences of simulated precipitation and clubmoss on soil and plant water relations.

Table 1. Mean canopy cover of plants in control plots at Dundurn in 1997 and Dundurn and Rudy in 1998.

		Canopy cover component						
Site	Year	Total cover	Total graminoids	Junegrass	Blue grama	Forbs	Clubmoss	Bare soil
		Canopy cover (%)						
Dundurn	1997	38	19	9	6	4	42	3
	1998	30	21	8	7	6	30	7
Rudy	1998	33	33	5	5	4	33	7
	Mean	33	24	7	6	5	35	6

Table 2. Mean monthly temperature and monthly precipitation received at Outlook, Saskatchewan, near Dundurn and Rudy, from September 1996 through September 1998. Data are from Saskatchewan Irrigation Development Center at Outlook, Saskatchewan.

	Month												
Years	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Total
	Precipitation (mm)												
1996-97	56	6	23	17	16	36	8	25	18	80	6	34	325
1997-98	35	5	3	5	1	4	3	7	12	112	21	74	282
	Temperature (°C)												Mean
1996-97	10.2	2.4	-12.6	-19.4	-21.1	-8.4	-6.7	3.1	11.1	17.5	19.0	18.7	1.2
1997-98	15.0	5.4	-4.0	-5.7	-16.3	-5.6	-4.8	8.2	13.3	15.2	20.3	20.7	5.1

Sward disturbance study

Sward disturbances were applied in a 3 x 5 factorial in randomized complete block design with 4 replicates. This study was conducted at Dundurn in 1997 and was repeated in 1998 at Rudy. The Dundurn and Rudy sites were about 2 km apart. Data were collected the first growing season following sward disturbances at both sites; second year data were also collected in 1998 at Dundurn. Disturbances were applied to 3 x 3 m plots, but measurement of independent variables was restricted to a 2 x 2 m area centered in each plot. A 2 m buffer separated all plots.

Sward disturbances included: 1) mechanical; 2) nitrogen added; 3) clubmoss killed with glyphosate; 4) clubmoss removed, and; 5) control. Disturbances were applied once in April 1997 at Dundurn and in April 1998 at Rudy.

Mechanical disturbance, or cultivation, was chosen because it is currently being used in Northern Mixed Prairie to reduce clubmoss. Plots were mechanically disturbed by cultivating; shovels of the cultivator were spaced 30 cm apart. One pass was made over plots and maximum depth of disturbance was about 10-15 cm.

The nitrogen disturbance was completed by adding 30 kg N ha^{-1} as ammonium nitrate (NO_3^-) in April and June on plots disturbed in 1997 or 1998 for a total of 60 kg ha^{-1} actual nitrogen added per year. This rate was chosen to equal the amount of nitrogen predicted to be liberated by mechanical disturbance (Rennie *et al.* 1993). Adding inorganic nitrogen at a rate equal to that which is liberated following mechanical disturbance was intended to help determine if mechanically removing clubmoss caused response, or if observed changes in the plant community were due to increased soil nitrogen. Ammonium nitrate was dissolved in about 5 L of water, and the solution was applied with a watering can.

Clubmoss was killed with glyphosate, applied with water as a 33% solution using hand-held spray bottles. Glyphosate was restricted from contacting other plants in the sward by holding spray bottles at ground level and spraying only clubmoss in the 3 x 3 m plot. This disturbance was chosen to determine if the physical presence of clubmoss alters soil and plant water status and production.

Clubmoss was removed from plots using garden rakes to uproot plants. Uprooted clubmoss was removed from plots using a flexible-toothed leaf-rake. In some areas within each plot, patches of clubmoss could not be removed with the garden rake without disturbing other plants. In these areas, a small hand-held weeding tool with 3 prongs was used to uproot clubmoss without killing other plants. This disturbance was chosen to determine if removing clubmoss from the sward impacted soil and plant water relations. Clubmoss from 1 m^2 was collected and weight determined after oven drying for 48 hours at 80°C.

No disturbance was applied to control plots. These plots consisted of naturally occurring plant communities.

Sward disturbances were factorially combined with three precipitation treatments: 1) ambient or natural precipitation, water added by irrigating, or precipitation reduced. Plots receiving ambient precipitation were not irrigated and served as control for precipitation treatments. Irrigating plots simulated above-average precipitation years, whereas reducing water amplified seasonal drought. These treatments were intended to determine whether clubmoss or precipitation had greater effects on soil water, plant water status, and production.

On plots with water added, ambient precipitation was supplemented with one application of 40 mm of water in mid-May, mid-June, mid-July, and mid-August of 1997 and 1998. In total 160 mm more water than ambient precipitation were added to each plot over the summer. This additional water is about 75% greater than long-term mean precipitation received from April through August in this area (Environment Canada 1982). Plots were irrigated with fresh water applied to the 3 x 3 m plots at a rate of about 45 L min^{-1}. Amount and rate of irrigation was controlled using a gas-powered pump and a hose with an adjustable nozzle. It was necessary to stop adding water for 3-5 minutes part way through application to prevent water from running off plots. Infiltration of water in this sandy soil was rapid and little or no water was lost to runoff.

Rain-out shelters were constructed to decrease the amount of precipitation reaching plots in the treatment of water reduced. Rain-out shelters were constructed using 4-2 x 4s, which were placed on edge, to make a 3 x 3m frame. Two additional 2 x 4s were placed through the center of each shelter for strength. One support beam was placed on edge inside the frame and fastened to the frame at each end. A second support beam was placed flat on top of the frame, running perpendicular to the first support beam. Greenhouse plastic (5 mm) was cut to leave 25-30 cm overhanging on all sides of the frame. Once centered over the frame, the plastic was fastened to the upper support beam first by placing 100 x 4 x 0.5 cm laths over the plastic and nailing them to the 2 x 4. Plastic on sides 1 and 3 was then secured to the frame of the shelter by wrapping it around laths until tight between the center beam and the edge of the frame. The plastic-wrapped laths were nailed to the frame. This procedure was repeated on the other 2 sides of the shelter. Rain-out shelters were positioned about 1.0-1.2 m above ground by fastening them to posts in each corner. Rain-out shelters were put up on 22 May 1997 at Dundurn and taken down for winter in October 1997. In 1998, rain-out shelters were put up on 3 April at Dundurn and on 10 April at Rudy.

Soil water and mid-day leaf xylem water potentials were measured at two-week intervals from May through August in the first growing season following sward disturbance at Dundurn and Rudy, and in the second year (1998) after disturbance at Dundurn. Mid-day leaf xylem water potentials were measured between 1100-1400 h using a pressure chamber (Ritchie and Hinckley 1975). In May and June, the uppermost fully expanded leaf of one Junegrass tiller in each plot was selected whereas in July and August, one blue grama tiller from each plot was selected for measurement. Blue grama tillers with two- to four-fully emerged leaves were chosen in all plots. These species were chosen for leaf xylem water potentials because Junegrass, a C_3, grows in May and June, and the C_4 blue grama grows in July and August, therefore by using both species, plant water status could be continuously measured throughout the growing season. Leaves of Junegrass were excised 3-4 mm above the collar, whereas blue grama tillers were excised 3-4 mm above ground level. Leaf xylem water potentials were determined immediately after excision, and measurements were completed on a block-by-block basis to minimize differences among treatments.

Soil was collected in each plot at the 0-30 cm depth on the same day that mid-day leaf xylem water potentials were determined using a soil core with a 1.5cm diameter. Soil was placed in soil tins, sealed, and transported to the laboratory. Cans were weighed, dried at 80 °C for 48 hours, re-weighed and gravimetric water content was calculated.

A pressure plate was used to determine water content at field capacity (-0.03 MPa) and permanent wilting point (-1.5 MPa) for the 0-30 cm depth of the soil profile. Respectively, soil water content at -0.03 and -1.5 MPa averaged 8.5 % (SE± 0.47) and 6.9 % (SE±0.43) at Dundurn, and 8.1 % (SE±0.42) and 7.4% (SE±0.41) at Rudy.

Total cover and cover of clubmoss, forbs, graminoids and bare ground was estimated for each plot following Daubenmire (1959). Cover was estimated monthly in a 20 x 50 cm quadrat for each plot from May through August 1997, and from May through July 1998. Cover-midpoints (Daubenmire 1959) were used to determine means of cover components.

Peak standing crop was determined at Dundurn in August 1997 and July 1998, and at Rudy in July 1998. Quadrats, 50 x 50 cm in size, were randomly located within the 2 x 2 m sample area of each plot, current growing season biomass was clipped at ground level, sorted, and placed in paper bags. Standing dead material from previous growing seasons was considered litter and excluded from estimates, but dormant and mature plants from the current growing season were included in biomass estimates. Samples were dried at 80°C for 48 hours and weighed.

Allocation of above-ground biomass was determined for Junegrass in June 1997 and June 1998 and for blue grama in July 1997 and August 1998. Within one week following anthesis, three tillers were selected from Junegrass and blue grama in each plot, clipped at ground level, placed in paper envelopes, and dried at 80°C for 48 hours. Culms and inflorescence of tillers were separated and weighed.

Phenological development of Junegrass and blue grama was assessed every two to three weeks from May through July at Dundurn in 1997 and 1998, and at Rudy in 1998. Three growth stages were used to describe phenological development of plants. Phenological stages of plants were classified into: 1) vegetative, 2) culm elongation, 3) or reproductive (Moore 1991). Within each stage, several sub-stages were used to describe plant phenology. The number of sub-stages in vegetative and elongation stages equals the number of morphological events occurring for each species within a particular environment. The vegetative stage includes leaf growth and development (Moore 1991). Successive sub-stages refer to the number of fully emerged and live leaves present. Leaves were considered fully emerged when the collar was fully developed. Senesced leaves were not considered when assigning sub-stages to tillers. Culm elongation sub-stages were identified by the visible number of nodes. This stage ceases when the inflorescence is enclosed in the uppermost leaf sheath. The reproductive stage begins when inflorescences emerge, and continues through anthesis. To assess floral development during reproductive stage, spikelets about one-half way between the lower-most spikelet and apex of the inflorescence were observed.

Numerical indices were determined for each sub-stage within primary stages for quantitative analysis. Numerical indices for reproductive stages are arbitrarily assigned (Moore 1991). Indices for vegetative and elongation stages are dependent upon the number of morphological events (N) occurring within each tiller for each species and is calculated as (Equation 2); where P is the primary growth stage number (1 or 2 for vegetative and elongation respectively), and n is the event number (Moore 1991).

Anion exchange membranes (Qian and Schoenau, 1995) were used to determine *in situ* supply rate of NO_3^- nitrogen at Dundurn in 1997, and at Dundurn and Rudy in 1998. Each anion exchange resin membrane was enclosed in a plastic frame measuring 15.2 x 2.8 x 0.5 cm. Exchange membranes were saturated with sodium bicarbonate (HCO_3^-) by soaking in 0.5 M $NaHCO_3$ (pH 8.5) for 12-14 hours (Qian and Schoenau 1995). One probe was inserted into the soil in each plot in June of 1997 and 1998 and was removed after 14 days. Soil was washed from each probe in field using deionized water. Probes were taken to the laboratory, each was transferred to a clean plastic bag, and 20 ml of 0.5 M HCl added to remove adsorbed ions. Inorganic nitrogen (NO_3^-) in the 0.5 M HCl was determined colorimetrically using a Technicon Autoanalyzer System. The amount of NO_3^- exchanged with HCO_3^- on the membrane surface is expressed as μg cm^{-2} $week^{-1}$ (Jowkin and Schoenau 1998). The value obtained from each anion exchange membrane represents the amount of nitrogen available to plants over the burial period, not the amount in the soil during that time.

Simulated precipitation study

Treatment design of the simulated precipitation study was a 2 x 7 factorial in a randomized complete block with 4 replicates. This study was conducted in May, June, and July 1997 at Dundurn and in May, June, July, and August 1998 at Rudy. New study plots were established each month the study was conducted.

Sward treatments consisted of clubmoss removed with a rake and control. Plots were 85 x 85 cm in size. Clubmoss was removed 10-14 days before each study was begun, and before 5 x 5 m rain-out shelters were placed over each replicate as in the sward disturbance study. Precipitation treatments consisted of single application of 0.0, 0.5, 2.5, 5.0, 10.0, 15.0, 20.0, or 25.0 mm of water in each month of study. The appropriate amount of water for each treatment was applied using garden watering cans. Soil water and mid-day leaf xylem water potentials of Junegrass or blue grama were measured before applying water (day 0) and 1, 2, 4 and 7 days after applying water. Soil water and mid-day leaf xylem water potentials were measured using methods described earlier. Soil water was determined for 0-3 and 3-30 cm depths of the profile. Measurements of soil water and leaf xylem water potentials were restricted to the inner 50 x 50 cm of each 85 x 85 cm plot.

Data analysis

Data from the sward disturbance study were analyzed with analysis of variance in randomized complete block design followed by linear contrasts of means (Steel and Torrie 1980). Data of soil water and mid-day leaf xylem water potentials were analyzed within dates of determination and for the average of all dates over the summer. Six linear contrasts of sward disturbances and 3 contrasts for precipitation treatments were used to test for differences ($P \leq 0.05$) between main effects. Six contrasts of sward disturbance were: 1) clubmoss present vs. clubmoss removed; 2) dead clubmoss present vs. clubmoss removed; 3) clubmoss present vs. clubmoss dead; 4) nitrogen added vs. clubmoss present; 5) mechanical disturbance vs. clubmoss present; and 6) mechanical disturbance vs. nitrogen added. Three additional contrasts for precipitation treatments were: 1) water added vs. ambient precipitation; 2) water reduced vs. ambient precipitation, and; 3) water added vs. water reduced.

In addition to the previous 9 contrasts, 18 more contrasts were used to test for differences ($P < 0.05$) between interaction of main effects by comparing interaction of 2 precipitation treatments to the interaction of 2 sward disturbances (included in Appendix A). For example, water contrast 1 compared to sward disturbance 1, as described above, is: (water added x ambient precipitation vs. clubmoss present x clubmoss removed). This step was repeated to combine the 3 contrasts for water main effects with the 6 contrasts of sward disturbance main effects. These additional 18 contrasts were selected to determine if individual sward disturbances reacted the same under all three water amounts. For example, the example contrast above determines if adding water or ambient precipitation had greater effect on an independent variable when clubmoss was present or removed.

Data for the simulated precipitation study were analyzed with analysis of variance followed by linear contrasts (Steel and Torrie 1980). Eighteen contrasts were chosen to analyze data collected on the 5 dates for each replication of the experiment. Seven contrasts compared soil water and mid-day leaf xylem water potentials in the treatments of clubmoss present or removed at each of the 6 amounts of water. Twelve additional contrasts compared the control for the water treatment (0.0 mm added) with each of the other 6 precipitation treatments for plots with clubmoss present or removed (12 contrasts total) (Appendix B).

Results

Sward disturbance study

Plant community characteristics

With the exception of Dundurn in 1997, mechanical disturbance or removal of clubmoss reduced cover of clubmoss and litter and increased the amount of bare soil (Table 3). Total canopy cover, excluding clubmoss, and that of forbs and graminoids was not affected by sward disturbance. Interacting effects of sward and precipitation treatments on canopy cover components were not significant for most comparisons ($P > 0.05$) (Appendix A).

Sward disturbances and precipitation treatments influenced the plant community composition differently. At both study sites, disturbances had a greater effect on canopy cover than precipitation treatments. Plant community composition after mechanical disturbance or removing clubmoss was similar while composition in control, clubmoss killed, and nitrogen disturbances were similar (Figure 1). The major differences in composition between these two groupings of disturbances were the amount of bare ground and clubmoss cover (Table 3, Appendix A).

Soil water and mid-day leaf xylem water potentials

Precipitation received in May through August at Dundurn in 1997 was 86% greater in the irrigation treatment than control, and less than 2% of control when precipitation was reduced (Table 4). In 1997 most precipitation was received in June and August and the least in May and July. At Rudy and Dundurn in 1998, precipitation in the irrigation treatment was about 91% greater than control, and no precipitation was recorded in the treatment of reduced precipitation. In 1998, most precipitation was received in July and the least was recorded in May.

Contrasts of sward disturbances and precipitation treatments indicated that reducing precipitation had the most consistent effect on soil water and leaf xylem water potentials. Interacting effects of sward disturbances and precipitation treatments on soil water and leaf xylem water potentials were not significant ($P > 0.05$) in most cases (Appendix A). Disturbing the sward had no consistent effect on soil water and leaf xylem water potentials. As expected, soil water was consistently increased by irrigation and decreased by reducing precipitation. Soil water content and leaf xylem water potentials varied widely among dates, but they tended to decline over the summer regardless of sward disturbance or water treatment (Tables 5-13).

Except on 8 July 1997 when soil water was greater on plots with clubmoss killed at Dundurn, killing clubmoss did not influence ($P > 0.05$) soil water compared to removing clubmoss from the sward (Tables 6 and 8). Soil water in control was greater on 3 of 8 dates and when averaged over the summer, relative to the nitrogen treatment. Mechanical disturbance increased soil water on 3 of 8 dates compared to adding nitrogen. Reducing precipitation consistently reduced soil water relative to control and irrigation.

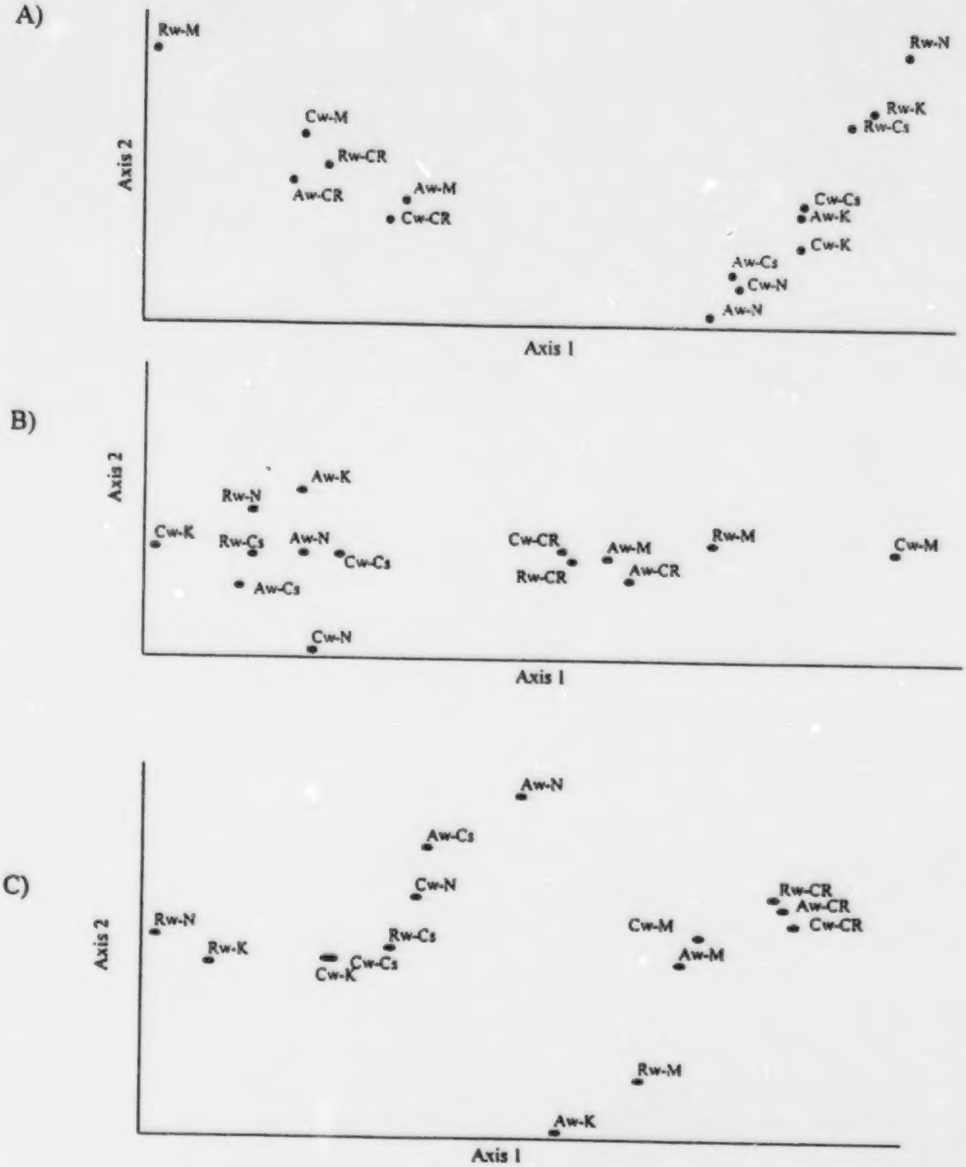

Figure 1. Ordination of plant communities created by five sward disturbances and three precipitation treatments at Dundurn in July 1997 (A), Rudy in July 1998 (B), and Dundurn in July 1998 (C). Precipitation treatments are CW-Control, Rw-Precipitation reduced, and Aw-Irrigated. Sward disturbances are Cs-Control, N-Nitrogen added, CR-Clubmoss removed, K-Clubmoss killed, and M-Mechanical. Data used in the ordination are included in Appendix A.

Table 3. Canopy cover for 5 sward disturbances averaged over 3 precipitation treatments at Dundurn in 1997 and 1998, and Rudy in 1998.

			Sward disturbance					
Site	Year	Cover component	Control	Nitrogen added	Clubmoss killed	Mechanical disturbance	Clubmoss removed	SE
			Canopy cover (%)					
Dundurn	1997	Clubmoss	52	52	60	56	19	35
		Litter	11	11	7	8	5	8
		Bare ground	5	5	3	3	46	13
		Forbs	14	14	14	15	8	6
		Graminoids	27	27	21	16	12	23
		Total forbs and graminoids	41	41	35	31	20	27
	1998	Clubmoss	32	36	34	22	15	3
		Litter	40	39	36	19	36	35
		Bare ground	3	3	3	56	23	3
		Forbs	13	14	10	10	1	15
		Graminoids	29	25	21	24	23	27
		Total forbs and graminoids	42	39	31	34	34	52
Rudy	1998	Clubmoss	38	32	26	15	15	2
		Litter	18	19	40	9	10	19
		Bare ground	6	6	6	58	54	72
		Forbs	7	6	6	4	8	26
		Graminoids	24	27	19	18	19	54
		Total forbs and graminoids	31	33	25	22	27	38

Table 4. Precipitation (mm) received during the study from May through August 1997 and 1998.

		Precipitation treatment					
Month	Time of month (days)	Ambient conditions		Precipitation reduced		Irrigated	
		Precipitation (mm)					
		--1997--	--1998--	--1997--	--1998--	--1997--	--1998--
May	1-5	----[1]	----[1]	----[1]	----[1]	----[1]	----[1]
	6-10	----	----	----	----	(40)[2]	(40)[2]
	11-15	0.0	0.0	----	0.0	0.0	0.0
	16-20	5.0	11.0	----	0.0	5.0	11.0
	21-25	5.1	0.0	2.0	0.0	5.1	0.0
	26-31	0.0	2.0	0.0	0.0	0.0	2.0
June	1-5	0.0	9.0	0.0	0.0	0.0	9.0
	6-10	33.0	0.0	0.0	0.0	33.0(40)	0.0(40.0)
	11-15	0.0	0.0	0.0	0.0	0.0	0.0
	16-20	15.0	0.0	0.0	0.0	15.0	0.0
	21-25	32.0	0.0	0.0	0.0	32.0	0.0
	26-30	11.5	58.0	0.0	0.0	11.5	58.0
July	1-5	1.0	59.0	0.0	0.0	1.0	59.0
	6-10	4.0	10.0	0.0	0.0	4.0(40)	10.0(40)
	11-15	0.0	0.0	0.0	0.0	0.0	0.0
	16-20	0.0	0.0	0.0	0.0	0.0	0.0
	21-25	2.0	0.0	0.0	0.0	2.0	0.0
	26-31	0.0	0.0	0.0	0.0	0.0	0.0
August	1-5	0.0	0.0	0.0	0.0	0.0	0.0
	6-10	7.0	0.0	0.0	0.0	7.0(40)	0.0(40)
	11-15	68.5	12.0	0.0	0.0	68.5	12.0
	16-20	0.0	0.0	0.0	0.0	0.0	0.0
	21-25	2.0	18.0	0.0	0.0	2.0	18.0
	26-31	0.0	0.0	0.0	0.0	0.0	0.0
Total		186.1	179.0	2.0	0.0	346.1	339.0

[1] ---indicates precipitation data were not recorded.

[2] (40) indicates 40 mm of additional precipitation was supplied by irrigating during this time frame.

Table 5. Soil water in the 0-30 cm depth on 8 dates for 3 precipitation treatments and 5 sward disturbances in the first year for plots disturbed in April 1997 at Dundurn.

		Sward disturbance						
Precipitation treatment	Date	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]
		Soil water (%)						
Control	May 9	9.6	10.7	10.5	9.4	9.9	10.0	
Reduced		8.8	9.4	11.3	10.1	11.0	10.1	
Irrigation		10.8	10.4	10.7	10.4	10.8	10.6	0.29
Mean		9.7	10.1	10.8	10.0	10.6		0.37
Control	20	10.0	9.8	10.9	9.1	8.4	9.6	
Reduced		9.8	7.3	9.1	9.3	9.6	9.0	
Irrigation		11.6	11.1	10.9	11.6	11.6	11.3	0.38
Mean		10.4	9.4	10.3	10.0	9.9		0.49
Control	Jun. 9	9.5	9.8	10.8	10.6	9.2	10.0	
Reduced		9.0	4.3	8.2	9.5	9.9	8.2	
Irrigation		12.4	8.9	10.9	9.6	10.4	10.4	0.64
Mean		10.3	7.7	10.0	9.9	9.8		0.83
Control	26	10.3	10.3	11.0	11.5	9.0	10.4	
Reduced		5.3	5.7	7.3	8.2	8.0	6.9	
Irrigation		11.3	10.7	11.1	9.3	10.6	10.6	0.52
Mean		8.9	8.9	9.8	9.7	9.2		0.67
Control	Jul. 8	7.9	6.9	9.1	7.7	6.7	7.7	
Reduced		3.3	3.2	4.9	5.0	4.3	4.1	
Irrigation		8.9	7.5	8.4	8.4	7.7	8.2	0.28
Mean		6.7	5.9	7.5	7.0	6.2		0.36
Control	26	3.8	3.0	3.5	4.0	3.3	3.5	
Reduced		2.7	2.0	3.4	3.6	3.3	3.0	
Irrigation		4.9	4.0	4.0	3.6	4.2	4.1	0.23
Mean		3.8	3.0	3.6	3.7	3.6		0.29
Control	Aug. 5	1.6	1.7	1.9	1.5	1.5	1.6	
Reduced		1.6	1.5	1.5	1.9	1.8	1.7	
Irrigation		1.4	1.4	1.7	1.6	1.7	1.6	0.08
Mean		1.5	1.5	1.7	1.7	1.7		0.11
Control	21	10.2	9.6	9.9	9.5	9.0	9.6	
Reduced		8.5	4.8	6.0	6.1	6.6	6.4	
Irrigation		9.4	8.9	8.6	8.2	9.4	8.9	0.34
Mean		9.4	7.8	8.2	7.9	8.3		0.44
Control	Average[2]	7.8	7.7	8.4	7.9	7.1	7.8	
Reduced		6.1	4.8	6.4	6.7	6.8	6.2	
Irrigation		8.8	7.8	8.3	7.8	8.3	8.2	0.30
Mean		7.6	6.8	7.7	7.5	7.4		0.33

[1] Within dates upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

[2] Average within treatments over 8 dates.

Table 6. Mid-day leaf xylem water potentials of Junegrass and blue grama on 8 dates for 3 precipitation amounts and 5 sward disturbances at Dundurn for plots disturbed in April 1997.

			Sward disturbance						
Precipitation treatment	Species	Date	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]
			Leaf xylem water potential (-MPa)						
Control	Junegrass	May 9	1.1	0.9	1.4	1.7	1.4	1.3	
Reduced			1.5	1.7	1.2	1.4	1.7	1.5	
Irrigation			1.9	1.2	1.6	1.6	1.1	1.5	0.09
Mean			1.5	1.3	1.4	1.5	1.4		0.18
Control		20	0.9	0.9	1.0	1.1	1.1	1.0	
Reduced			0.8	0.6	0.8	0.7	1.0	0.8	
Irrigation			1.1	1.2	1.0	0.9	0.6	0.9	0.04
Mean			0.9	0.9	0.9	0.9	0.9		0.12
Control		Jun. 9	1.9	1.7	2.0	1.9	1.9	1.9	
Reduced			2.0	2.2	2.1	2.3	2.0	2.1	
Irrigation			2.1	1.9	1.7	2.2	2.4	2.1	0.03
Mean			2.0	1.9	1.9	2.1	2.1		0.11
Control		26	2.3	2.3	2.0	2.3	2.2	2.2	
Reduced			2.9	3.3	2.4	2.3	2.7	2.7	
Irrigation			2.3	2.0	2.3	2.2	1.8	2.1	0.07
Mean			2.5	2.5	2.2	2.3	2.2		0.16
Control	blue grama	Jul. 8	0.8	1.3	1.0	0.8	1.3	1.0	
Reduced			2.6	2.9	2.4	1.6	2.0	2.3	
Irrigation			1.1	1.1	0.9	1.1	0.9	1.0	0.08
Mean			1.5	1.8	1.4	1.2	1.4		0.18
Control		26	1.1	1.4	3.2	0.7	0.9	1.1	
Reduced			2.8	3.3	0.6	2.4	2.6	2.9	
Irrigation			0.7	1.5	1.7	0.7	0.5	0.8	0.03
Mean			1.5	2.1	1.7	1.2	1.3		0.11
Control		5	4.8	4.9	4.5	5.2	4.7	4.8	
Reduced			6.0	4.8	5.8	5.0	5.7	5.4	
Irrigation			5.2	5.4	4.8	5.5	5.0	5.2	0.17
Mean			5.3	5.0	5.0	5.2	5.1		0.25
Control		Aug. 21	1.3	1.2	1.3	0.8	0.9	1.1	
Reduced			2.0	1.7	1.6	1.3	1.7	1.7	
Irrigation			0.8	1.1	1.0	1.1	1.3	1.0	0.05
Mean			1.4	1.3	1.3	1.1	1.3		0.14
Control	Average[2]		1.8	1.8	1.8	1.8	1.8	1.8	
Reduced			2.6	2.5	2.4	2.1	2.4	2.4	
Irrigation			1.9	1.9	1.7	1.9	1.7	1.8	0.01
Mean			2.1	2.1	2.0	1.9	2.0		0.07

[1] Within dates upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

[2] Average within treatments over 8 dates.

Table 7. Probabilities that contrasts of mean soil water in the 0-30 cm depth on 8 days are different among 3 precipitation treatments and 5 sward disturbances at Dundurn in April 1997. Bold values indicate means are different ($P \leq 0.05$).

	Date of determination								
	May		Jun.		Jul.		Aug.		
Treatment contrast	9	20	9	26	8	26	5	21	Average[3]
	Calculated probability								
Control (Cs)[1] vs. Clubmoss removed (CR)	0.186	0.333	0.580	0.738	0.434	0.554	0.363	0.147	0.626
Clubmoss killed (K) vs. (CR)	0.723	0.499	0.858	0.471	**0.032**	0.924	1.000	0.844	0.414
Cs vs. K	0.096	0.767	0.707	0.293	0.162	0.619	0.363	0.101	0.739
Nitrogen (N) vs. Cs	0.539	0.070	**0.003**	0.967	0.171	**0.023**	0.919	**0.030**	**0.038**
Mechanical (M) vs. Cs	0.723	0.456	0.621	0.348	0.531	0.758	0.419	0.051	0.762
M vs. N	0.793	0.274	**0.012**	0.327	**0.049**	**0.046**	0.479	0.817	0.073
Irrigation (Aw) vs. Control (Cw)[2]	0.216	**0.001**	0.496	0.752	0.267	**0.028**	0.638	0.192	0.173
Precipiiation Reduced (Rw) vs. Cw	0.823	0.176	**0.009**	**0.000**	**0.000**	**0.064**	0.783	**0.000**	**0.000**
Aw vs. Rw	0.308	**0.000**	**0.001**	**0.000**	**0.000**	**0.000**	0.457	**0.000**	**0.000**
	Leaf xylem water potential (MPa)								
Cs vs. CR	0.425	0.907	0.753	0.186	0.765	0.557	0.533	0.613	0.239
K vs. CR	0.850	0.954	0.420	0.937	0.834	0.254	0.861	0.910	0.769
Cs vs. K	0.541	0.954	0.621	0.162	0.928	0.575	0.426	0.537	0.374
N vs. Cs	0.176	0.684	0.501	0.906	0.298	0.097	0.398	0.694	0.900
M vs. Cs	0.850	0.771	0.653	0.292	0.259	0.387	0.842	0.054	0.167
M vs. N	0.125	0.907	0.264	0.242	**0.033**	**0.014**	0.517	0.121	0.132
Aw vs. Cw	0.193	0.686	0.214	0.485	0.945	0.247	0.147	0.761	0.702
Rw vs. Cw	0.181	0.070	0.100	**0.006**	**0.000**	**0.000**	**0.017**	**0.000**	**0.000**
Aw vs. Rw	0.971	0.155	0.676	**0.001**	**0.000**	**0.000**	0.317	**0.000**	**0.000**

[1] Control (Cs) is no sward disturbance.

[2] Control (Cw) is no precipitation manipulation.

[3] Average within treatments over 8 dates.

Table 8. Soil water in the 0-30 cm depth of the profile on 8 dates for 3 precipitation amounts and 5 sward disturbances at Rudy for plots disturbed in April 1998.

		Sward disturbance						
Precipitation Treatment	Date	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]
		Soil water (%)						
Control	May 7	5.5	5.8	6.1	4.6	3.6	5.1	
Reduced		6.2	4.2	4.9	5.6	4.4	5.0	
Irrigation		5.6	4.7	4.6	4.3	5.2	4.9	0.14
Mean		5.7	4.9	5.2	4.8	4.4		0.18
Control	21	4.5	4.7	5.1	4.2	3.5	4.4	
Reduced		4.0	2.8	3.2	4.1	3.1	3.4	
Irrigation		8.2	8.0	7.1	6.8	7.5	7.5	0.17
Mean		5.6	5.2	5.1	5.0	4.7		0.22
Control	Jun. 11	2.6	3.4	3.0	2.4	2.8	2.8	
Reduced		2.6	2.7	2.3	3.0	2.2	2.5	
Irrigation		2.8	3.1	3.2	2.8	3.2	3.0	0.20
Mean		2.6	3.1	2.8	2.7	2.7		0.26
Control	25	11.2	11.2	10.6	10.4	10.1	10.7	
Reduced		8.8	4.6	9.3	6.5	7.0	7.3	
Irrigation		11.1	9.8	10.2	8.7	10.7	10.1	0.21
Mean		10.4	8.5	10.0	8.5	9.3		0.27
Control	Jul. 9	12.5	12.0	12.2	12.2	10.4	11.8	
Reduced		8.1	8.5	9.6	15.1	9.8	10.2	
Irrigation		12.4	11.7	11.5	10.7	12.0	11.6	0.40
Mean		11.0	10.7	11.1	12.7	10.7		0.52
Control	28	2.2	2.4	2.3	2.0	1.7	2.1	
Reduced		1.9	1.5	1.8	1.9	1.5	1.7	
Irrigation		3.1	2.6	3.1	2.4	3.1	2.8	0.13
Mean		2.4	2.1	2.4	2.1	2.1		0.17
Control	Aug. 7	2.3	2.2	2.2	2.2	1.7	2.1	
Reduced		2.3	1.5	1.9	2.2	1.8	1.9	
Irrigation		2.4	2.4	2.3	2.3	2.5	2.4	0.13
Mean		2.3	2.0	2.1	2.2	2.0		0.17
Control	18	4.9	8.3	6.1	4.3	5.4	5.8	
Reduced		2.0	1.6	1.9	2.4	2.5	2.1	
Irrigation		9.8	9.0	8.6	9.0	9.2	9.1	0.42
Mean		5.6	6.3	5.5	5.2	5.7		0.54
Control	Average[2]	5.7	5.8	6.2	5.2	5.8	5.7	
Reduced		3.2	3.2	4.3	3.3	3.5	3.5	
Irrigation		6.8	6.4	6.9	6.9	6.6	6.7	0.06
Mean		5.2	5.1	5.8	5.1	5.3		0.15

[1] Within dates upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

[2] Average within treatments over 8 dates.

treatments (Tables 5 and 7). Irrigation, however, increased soil water relative to control on 20 May and 26 July, but the average over the summer was not different ($P>0.05$) in the 2 treatments.

Effects of sward disturbances on leaf xylem water potentials were similar among dates at Dundurn in 1997. Exceptions occurred in July when leaf xylem water potentials of blue grama were 0.6 and 0.9 MPa lower when nitrogen was added than when the sward was mechanically disturbed (Tables 6 and 7). Precipitation treatments more consistently affected leaf xylem water potentials than did sward disturbances. Relative to control and the irrigation treatment, leaf xylem water potentials of Junegrass and blue grama were 0.5 to 2.1 MPa lower when precipitation was reduced. Leaf xylem water potentials were similar ($P>0.05$) in control and the irrigation treatment on all dates.

At Rudy in 1998, soil water and leaf xylem water potentials were not usually affected by sward disturbances (Tables 8-10). Soil water increased with irrigation and decreased by reducing precipitation on most dates and averaged over the summer. Averaged over the summer, leaf xylem water potentials declined similarly by reducing precipitation and increased under irrigation. Contrasts of interacting effects of sward disturbances and precipitation treatments on soil water and leaf xylem water potentials were not significant ($P>0.05$) in most cases (Appendix A).

At Rudy in 1998, sward disturbances had few effects on soil water (Tables 8 and 10). Compared to control, soil water was generally declined as precipitation was reduced and increased by irrigating. Irrigating increased soil water on 4 of 8 dates and when averaged over the summer (Tables 9 and 11). Relative to control, reducing precipitation decreased soil water on 4 of 8 dates and when averaged over the summer. On 6 dates soil water was up to 7.0% greater under irrigation than under reduced precipitation, and the average for the summer was 3.2% greater in irrigated plots.

Mid-day leaf xylem water potentials were affected by sward disturbances on several dates at Rudy in 1998 (Tables 9 and 10). On 7 May, leaf xylem water potentials were 0.6 MPa lower on control than in plots with clubmoss killed. On 4 dates leaf xylem water potentials were 0.3 to 1.9 MPa lower in control than mechanically treated plots and averaged over the summer they were 0.5 MPa higher in control than mechanically disturbed plots. Response to mechanical disturbance at this site was variable as leaf xylem water potentials were 0.2 MPa higher on 9 July, 2.0 MPa lower on 7 August, and 0.4 MPa lower when averaged over the summer relative to plots with nitrogen added. Leaf xylem water potentials were more consistently affected by irrigating or reducing precipitation than by disturbing the sward. Irrigating increased leaf xylem water potentials between 0.2 and 3.1 MPa and 0.3 and 3.4 MPa relative to control and reducing precipitation, respectively. Leaf xylem water potentials averaged over the summer were 0.6 and 0.8 MPa greater for plants in irrigated plots than in the plots where precipitation was reduced or in control, respectively (Tables 9 and 10).

Table 9. Mid-day leaf xylem water potentials for Junegrass and blue grama on 8 dates for 3 precipitation amounts and 5 sward disturbances at Rudy for plots disturbed in April 1998.

			Sward disturbance						
Precipitation treatment	Species	Date	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]
			Leaf xylem water potential (-MPa)						
Control	Junegrass	May 7	2.3	1.8	1.7	1.9	2.2	2.0	
Reduced			2.1	1.7	1.4	1.8	1.9	1.7	
Irrigation			2.2	2.4	1.8	1.8	1.8	2.0	0.10
Mean			2.2	1.9	1.6	1.8	1.9		0.06
Control		21	2.0	2.3	2.0	2.0	2.6	2.1	
Reduced			2.1	2.9	2.2	1.9	2.2	2.2	
Irrigation			2.2	2.0	2.2	2.4	2.0	2.1	0.08
Mean			2.1	2.4	2.1	2.1	2.3		0.04
Control		Jun 11	3.5	3.8	2.7	2.9	3.1	3.2	
Reduced			2.5	3.3	3.3	3.2	2.4	2.9	
Irrigation			3.0	3.0	2.9	2.9	2.9	2.9	0.11
Mean			3.0	3.4	2.9	3.0	2.8		0.07
Control		25	1.3	0.7	1.1	1.2	0.9	1.0	
Reduced			1.3	1.2	2.1	1.9	1.2	1.5	
Irrigation			1.0	1.4	0.9	0.8	0.9	1.0	0.05
Mean			1.2	1.1	1.3	1.3	1.0		0.01
Control	blue grama	Jul. 9	1.6	1.3	1.2	1.2	1.3	1.3	
Reduced			1.5	1.7	1.5	1.2	1.7	1.5	
Irrigation			1.3	1.4	1.3	1.1	0.9	1.2	0.03
Mean			1.5	1.4	1.3	1.2	1.3		0.00
Control		22	2.2	1.9	2.1	2.0	2.5	2.1	
Reduced			3.0	2.2	2.6	2.0	10.1	4.0	0.09
Irrigation			1.8	2.2	1.6	1.5	1.8	1.8	0.05
Mean			2.3	2.1	2.1	1.8	4.8		
Control		Aug. 7	5.3	5.6	4.1	2.9	3.6	4.3	
Reduced			5.0	4.9	4.1	2.6	5.2	4.4	
Irrigation			4.1	4.2	4.5	3.3	5.0	4.2	0.30
Mean			4.8	4.9	4.2	2.9	4.6		0.54
Control		18	1.5	1.0	1.5	1.9	1.1	1.4	
Reduced			5.5	4.2	4.5	2.8	5.5	4.5	
Irrigation			1.0	1.2	0.9	0.6	0.9	0.9	0.41
Mean			2.6	2.1	2.3	1.8	2.5		0.98
Control	Average[1]		2.4	2.3	2.0	2.0	2.1	2.2	
Reduced			2.9	2.7	2.7	2.2	3.8	2.8	
Irrigation			2.1	2.2	2.0	1.8	2.0	2.0	0.05
Mean			2.5	2.4	2.2	2.0	2.6		0.02

[1] Within dates upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

[2] Average within treatments over 8 dates.

Table 10. Probabilities that contrasts of mean soil water in the 0-30 cm depth and mid-day leaf xylem water potentials are different on 8 dates among 3 precipitation amounts and 5 sward disturbances at Rudy for plots disturbed in April 1998. Bold values indicate means are different ($P \leq 0.05$).

	Date of determination								
	May		Jun.		Jul.		Aug.		
Treatment contrast	7	21	11	25	9	28	7	18	Average
	Soil water (%)								
Control (Cs)[1] vs. Clubmoss removed (CR)	**0.023**	0.074	0.806	0.169	0.796	0.122	0.061	0.813	0.718
Clubmoss killed (K) vs. (CR)	0.174	0.369	0.598	0.346	0.752	0.185	0.491	0.770	0.054
Cs vs. K	0.330	0.360	0.441	0.659	0.954	0.819	0.226	0.956	**0.024**
Nitrogen (N) vs. Cs	0.145	0.397	0.068	**0.023**	0.807	0.211	0.085	0.215	0.599
Mechanical (M) vs. Cs	0.110	0.278	0.673	**0.025**	0.155	0.131	0.560	0.598	0.678
M vs. N	0.884	0.808	0.154	0.983	0.098	0.789	0.246	0.080	0.912
Irrigation (Aw) vs. Control (Cw)[2]	0.588	**0.000**	0.357	0.330	0.815	**0.000**	**0.028**	**0.000**	**0.000**
Precipitation Reduced (Rw) vs. Cw	0.883	**0.013**	0.113	**0.000**	0.072	**0.023**	0.179	**0.000**	**0.000**
Aw vs. Rw	0.692	**0.000**	**0.015**	**0.000**	0.115	**0.000**	**0.001**	**0.000**	**0.000**
	Leaf xylem water potential (MPa)								
Cs vs. CR	0.192	0.299	0.452	0.371	0.173	0.131	0.672	0.662	0.379
K vs. CR	0.065	0.405	0.580	0.078	0.828	0.102	0.488	0.662	0.067
Cs vs. K	**0.002**	0.834	0.840	0.371	0.250	0.895	0.267	0.383	0.329
N vs. Cs	0.192	0.073	0.282	0.604	0.942	0.899	0.852	0.172	0.849
M vs. Cs	**0.043**	0.875	0.980	0.479	**0.014**	0.769	**0.000**	**0.026**	**0.031**
M vs. N	0.453	0.052	0.271	0.223	**0.017**	0.867	**0.000**	0.360	**0.048**
Aw vs. Cw	0.743	0.968	0.313	0.687	0.183	0.784	0.834	0.136	0.339
Rw vs. Cw	0.107	0.420	0.362	**0.001**	**0.029**	0.153	0.834	**0.000**	**0.000**
Cs vs. CR	0.054	0.397	0.922	**0.000**	**0.001**	0.091	0.675	**0.000**	**0.000**

[1] Control (Cs) is no sward disturbance.

[2] Control (Cw) is no precipitation manipulation.

Table 11. Soil water in the 0-30 cm depth of the profile on 8 dates in 1998 for 3 precipitation amounts and 5 sward disturbances at Dundurn for plots disturbed in April 1997.

		Sward disturbance						
Precipiation treatment	Date	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]
		Soil water (%)						
Control	May 7	5.0	4.6	5.3	5.2	5.6	5.1	
Reduced		4.5	4.5	5.3	5.4	5.1	4.9	
Irrigation		4.8	4.6	5.1	6.3	5.7	5.3	0.35
Mean		4.8	4.6	5.2	5.6	5.4		0.45
Control	21	4.9	4.7	5.3	5.0	5.2	5.0	
Reduced		2.7	3.1	3.8	3.7	3.0	3.3	
Irrigation		7.6	6.5	7.9	8.3	7.4	7.5	0.27
Mean		5.1	4.8	5.7	5.7	5.2		0.35
Control	Jun. 11	3.4	3.3	4.5	3.4	3.7	3.6	
Reduced		2.6	3.0	3.3	3.3	2.2	2.9	
Irrigation		3.7	2.9	4.7	4.8	3.5	3.9	0.15
Mean		3.2	3.0	4.2	3.8	3.1		0.19
Control	25	9.0	9.3	10.3	8.7	10.1	9.5	
Reduced		4.9	4.7	6.1	3.3	5.1	4.8	
Irrigation		10.2	8.6	10.6	9.1	9.7	9.6	0.51
Mean		8.0	7.5	9.0	7.0	8.3		0.66
Control	Jul. 9	11.5	12.2	11.4	10.9	11.4	11.5	
Reduced		5.9	5.2	7.7	4.7	7.9	6.3	
Irrigation		11.8	12.4	11.9	11.6	11.6	11.8	0.85
Mean		9.7	9.9	10.3	9.1	10.3		1.10
Control	28	2.4	2.4	2.3	2.0	2.0	2.2	
Reduced		1.5	1.4	2.6	1.9	1.2	1.7	
Irrigation		2.8	2.5	3.0	2.8	2.7	2.7	0.13
Mean		2.2	2.1	2.6	2.2	2.0		0.16
Control	Aug. 7	2.6	2.6	2.4	2.4	2.3	2.5	
Reduced		1.7	1.9	2.9	2.2	2.0	2.1	
Irrigation		2.8	2.5	2.7	2.5	2.5	2.6	0.10
Mean		2.3	2.3	2.6	2.4	2.3		0.12
Control	18	7.0	7.1	8.5	4.4	6.2	6.6	
Reduced		1.7	1.8	2.5	2.1	1.7	1.9	
Irrigation		11.1	11.1	9.7	9.4	10.3	10.3	0.46
Mean		6.6	6.7	6.9	5.3	6.1		0.60
Control	Average[2]	5.7	6.2	5.9	5.3	4.9	5.6	
Reduced		4.5	3.4	4.3	5.1	4.0	4.3	
Irrigation		6.9	6.4	6.3	5.9	6.6	6.4	0.31
Mean		5.7	5.4	5.5	5.4	5.2		0.34

[1] Within dates upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

[2] Average within treatments over 8 dates.

Table 12. Mid-day leaf xylem water potentials for Junegrass and blue grama on 8 dates in 1998 for 3 precipitation amounts and 5 sward disturbances in at Dundurn in 1998.

			Sward disturbance						
Precipitation Treatment	Species	Date	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]
			Leaf xylem water potential (-MPa)						
Control	Junegrass	May 7	1.9	1.8	2.3	1.9	1.6	1.9	
Reduced			2.1	2.4	1.9	2.1	2.1	2.1	
Irrigation			2.2	2.1	2.2	2.1	1.6	2.0	0.08
Mean			2.0	2.1	2.2	2.0	1.7		0.04
Control		21	2.0	2.2	2.0	2.4	2.0	2.1	
Reduced			2.3	2.1	2.1	2.3	2.2	2.2	
Irrigation			2.1	2.0	2.5	2.6	1.8	2.2	0.13
Mean			2.1	2.1	2.2	2.4	2.0		0.10
Control		Jun. 11	3.9	4.1	4.0	4.6	3.7	4.1	
Reduced			3.6	3.8	3.4	4.0	4.3	3.8	
Irrigation			3.6	3.6	3.7	4.1	3.8	3.7	0.17
Mean			3.7	3.8	3.7	4.2	4.0		0.16
Control		25	1.2	1.1	1.1	1.2	1.2	1.2	
Reduced			1.4	1.5	1.3	1.6	1.7	1.5	
Irrigation			1.2	1.2	1.1	1.0	1.3	1.1	0.15
Mean			1.3	1.2	1.2	1.2	1.4		0.13
Control	blue grama	Jul. 9	1.5	1.3	1.4	1.3	1.2	1.3	
Reduced			1.7	1.6	1.6	1.6	1.3	1.5	
Irrigation			1.4	1.4	1.4	1.5	1.1	1.3	0.07
Mean			1.5	1.4	1.4	1.4	1.2		0.03
Control		28	1.9	1.9	1.7	2.3	1.6	1.9	
Reduced			1.7	2.0	1.9	1.9	1.8	1.8	
Irrigation			1.7	1.4	1.6	1.4	1.7	1.6	0.86
Mean			1.8	1.8	1.7	1.9	1.7		4.29
Control		Aug. 7	5.0	4.8	4.1	4.0	4.6	4.5	
Reduced			5.3	4.2	5.7	5.8	4.2	5.0	
Irrigation			4.3	5.4	5.1	4.5	4.0	4.6	0.29
Mean			4.8	4.8	5.0	4.8	4.2		0.50
Control		18	2.0	1.8	1.6	2.2	1.4	1.8	
Reduced			2.9	4.9	6.1	4.7	4.8	4.7	
Irrigation			2.4	2.5	1.1	0.7	2.2	1.8	0.21
Mean			2.4	3.1	2.9	2.7	2.8		0.25
Control			2.4	2.4	2.3	2.5	2.2	2.3	
Reduced	Average[2]		2.6	2.8	3.0	3.0	2.8	2.8	
Irrigation			2.4	2.4	2.3	2.2	2.2	2.3	0.06
Mean			2.5	2.5	2.5	2.6	2.4		0.02

[1] Within dates upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

[2] Average within treatments over 8 dates.

At Dundurn in 1998, disturbing the sward had no consistent effect on soil water content and leaf xylem water potentials (Tables 11-13). Soil water was increased with irrigation and decreased by reducing precipitation. Soil water content and leaf xylem water potentials varied widely among dates, but generally declined through the summer.

On some dates, soil water varied among disturbances at Dundurn in 1998, but no consistent trend was noted (Table 11 and 13). On 7 May, soil water was greater with clubmoss removed than in control. Soil water was greater with clubmoss killed than removed on 11 June and 28 July. In plots with clubmoss killed, soil water was greater on 21 May and 11 June relative to control. Mechanically disturbing the sward increased soil water in May, but decreased soil water on 18 August compared to control (Tables 11 and 13).

Irrigating or reducing precipitation had greater effects on soil moisture than sward disturbances at Dundurn in 1998. Compared to control, reducing precipitation decreased soil water on 6 dates and irrigating increased soil water on 3 dates (Tables 11 and 13). Irrigating also increased soil water on 7 dates compared to reducing precipitation. Soil water averaged over the summer was greater on irrigated plots than control, less on plots with precipitation reduced than control, and greater under irrigation than under reduced precipitation.

Leaf xylem water potentials were not affected by sward treatments at Dundurn in 1998 (Tables 12 and 13). One exception occurred on 7 May when leaf xylem water potentials were 0.5 MPa lower with clubmoss killed than on control. Irrigating or reducing precipitation affected leaf xylem water potentials on several dates, including 28 July, when leaf xylem water potential was 0.3 MPa lower control than when irrigated, and 18 August when reducing precipitation decreased leaf xylem water potential 2.9 MPa relative to irrigation. Leaf xylem water potentials on 28 July and 7 August, were 0.2 and 2.9 MPa lower with precipitation reduced than with irrigation, respectively. Averaged over the summer, leaf xylem water potentials were 0.5 MPa lower in the treatment of reduced precipitation than in control or when irrigated.

Peak standing crop

Sward disturbances, precipitation treatments, and their interactions (Appendix A) had no consistent affect on peak standing crop. The exception was the increase of graminoid production from between 25 and 36 g m^{-2} when irrigated compared to reducing precipitation, implying a strong influence was exerted by site or environmental conditions (Tables 14 and 15) (Appendix A).

At Dundurn in 1997, standing crop of graminoids and forbs was reduced by clubmoss removal relative to control; total standing crop and that of graminoids was reduced by mechanical disturbance (Tables 14 and 15). Peak standing crop of forbs was 35% less when clubmoss was killed than if clubmoss was removed. Irrigating or reducing precipitation had no influence ($P > 0.05$) on standing crop at Dundurn in 1997.

Table 13. Probabilities that contrasts of mean soil water in the 0-30 cm depth and mid-day leaf xylem water potentials are different on 8 dates in 1998 among 3 precipitation amounts and 5 sward disturbances at Dundurn for plots disturbed in April 1997. Bold values indicate means are different ($P \leq 0.05$).

	Date of determination								
	May		Jun.		Jul.		Aug.		
Treatment contrast	7	21	11	25	9	28	7	18	Average
	Soil water (0-30 cm)								
Control (Cs)[1] vs. Clubmoss removed (CR)	**0.036**	0.651	0.773	0.718	0.505	0.301	0.720	0.373	0.140
Clubmoss killed (K) vs. (CR)	0.541	0.106	**0.002**	0.394	0.968	**0.020**	0.100	0.145	0.326
Cs vs. K	0.128	**0.041**	**0.004**	0.228	0.480	0.180	0.193	0.561	0.613
Nitrogen (N) vs. Cs	0.524	0.353	0.619	0.530	0.824	0.550	0.936	0.858	0.316
Mechanical (M) vs. Cs	**0.011**	**0.047**	0.054	0.220	0.408	0.950	0.842	**0.030**	0.408
M vs. N	**0.002**	**0.005**	**0.017**	0.544	0.296	0.509	0.780	**0.019**	0.859
Irrigation (Aw) vs. Control (Cw)[2]	0.537	**0.000**	0.276	0.804	0.557	**0.014**	0.442	**0.000**	**0.003**
Precipitation Reduced (Rw) vs. Cw	0.435	**0.000**	**0.003**	**0.000**	**0.000**	**0.022**	0.057	**0.000**	**0.000**
Aw vs. Rw	0.166	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.009**	**0.000**	**0.000**
	Leaf xylem water potentials								
Cs vs. CR	0.075	0.473	0.362	0.814	0.378	0.649	0.159	0.557	0.338
K vs. CR	**0.017**	0.283	0.330	0.557	0.518	0.820	0.086	0.855	0.107
Cs vs. K	0.514	0.719	0.950	0.724	0.812	0.820	0.748	0.443	0.501
N vs. Cs	0.880	0.928	0.681	0.906	0.746	0.964	0.872	0.311	0.488
M vs. Cs	1.000	0.110	0.068	0.906	0.547	0.820	0.290	0.948	0.292
M vs. N	0.880	0.093	0.151	1.000	0.779	0.785	0.369	0.343	0.716
Aw vs. Cw	0.230	0.727	0.134	0.971	0.854	**0.013**	0.792	0.911	0.709
Rw vs. Cw	0.078	0.701	0.253	0.247	0.463	0.888	0.102	**0.000**	**0.000**
Aw vs. Rw	0.559	0.972	0.714	0.233	0.360	**0.019**	0.059	**0.000**	**0.000**

[1] Control (Cs) is no sward disturbance.

[2] Control (Cw) is no precipitation manipulation.

Table 14. Peak standing crop of graminoids, forbs, and total phytomass for 3 precipitation treatments and 5 sward disturbances at Dundurn in 1997 and at Dundurn and Rudy in 1998.

	Dundurn														Rudy						
	1997							1998							1998						
	Sward treatment																				
Precip. treatment	Control	Nitrogen added	Clubmoss killed	Mech-anical	Clubmoss removed	Mean	Standard error²	Control	Nitrogen added	Clubmoss killed	Mech-anical	Clubmoss removed	Mean	Standard error²	Control	Nitrogen added	Clubmoss killed	Mech-anical	Clubmoss removed	Mean	Standard error²
	Graminoids ($g\ m^{-2}$)																				
Control	25.2	25.0	22.0	14.2	12.9	19.9		65.7	52.8	75.5	95.5	47.0	67.4		80.5	80.8	54.5	76.3	53.0	69.0	
Reduced	17.6	16.6	18.9	14.5	14.1	16.3		44.3	31.5	42.3	59.0	52.0	45.8		56.3	48.5	40.8	27.8	57.8	46.2	
Irrigation	119.8	22.9	26.4	16.2	24.1	41.9	10.9	68.0	61.0	100.3	82.3	71.0	76.5	5.0	71.3	103.3	105.3	74.3	57.0	82.2	7.6
Mean	54.2	21.5	22.4	15.0	17.0		14.0	58.7	48.4	72.7	78.9	56.7		6.5	69.3	77.5	66.8	59.4	55.9		9.8
	Forbs ($g\ m^{-2}$)																				
Control	2.7	9.0	5.8	13.0	24.0	10.9		27.3	53.3	41.5	68.5	65.8	52.5		17.3	21.8	13.3	19.0	20.0	18.3	
Reduced	8.9	21.7	20.5	9.2	14.8	15.0		68.0	44.8	59.0	97.5	43.8	62.6		20.3	37.8	16.8	15.5	14.8	21.0	
Irrigation	14.2	13.4	9.9	8.0	18.5	12.8	2.6	41.3	53.0	44.5	31.0	58.8	45.7	8.1	24.5	19.3	16.3	27.3	36.5	24.8	3.4
Mean	8.6	14.7	12.1	10.0	19.1		3.4	47.2	50.3	48.3	65.7	56.1		10.5	20.7	26.3	15.4	20.6	23.8		4.4
	Total phytomass ($g\ m^{-2}$)																				
Control	27.9	34.0	27.8	27.3	36.9	30.8		92.7	106.5	117.0	164.3	113.0	120.1		97.8	102.5	67.8	95.3	73.0	87.3	
Reduced	26.5	38.3	39.4	23.7	28.9	31.4		112.3	76.3	101.3	156.8	96.0	108.5		76.5	86.3	57.5	43.3	72.5	67.2	
Irrigation	134.1	36.2	36.3	24.1	42.6	54.7	12.2	109.3	113.8	144.5	113.3	111.8	118.5	9.0	95.8	122.5	121.5	101.5	93.5	107.0	6.5
Mean	62.8	36.2	34.5	25.0	36.2		15.7	105.8	98.8	120.9	144.8	106.9		11.6	90.0	103.8	82.3	80.0	79.7		8.4

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[1] Refers to year of disturbance application

[2] Within biomass components upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

Table 15. Probabilities that contrasts of mean graminoid, forb, and total phytomass are different for 3 precipitation treatments and 5 sward disturbances at Dundurn in 1997 and at Dundurn and Rudy in 1998. Bold values indicate contrasts are different ($P \leq 0.05$).

	Dundurn						Rudy		
	1997			1998			1998		
Treatment contrast	Graminoids	Forbs	Total	Gram-inoids	Forbs	Total	Gram-inoids	Forbs	Total
	Calculated probability								
Control (Cs)[1] vs. Clubmoss removed (CR)	**0.046**	**0.003**	0.162	0.756	0.296	0.450	0.144	0.670	0.304
Clubmoss killed (K) vs. (CR)	0.766	**0.039**	0.930	0.084	0.526	0.288	0.233	0.253	0.796
Cs vs. K	0.085	0.303	0.138	**0.044**	0.677	0.073	0.783	0.470	0.439
Nitrogen (N) vs. Cs	0.077	0.073	0.162	0.553	0.562	0.889	0.370	0.442	0.173
Mechanical (M) vs. Cs	**0.035**	0.667	**0.050**	**0.008**	0.072	**0.001**	0.278	0.991	0.320
M vs. N	0.721	0.167	0.555	**0.002**	0.213	**0.001**	0.051	0.435	**0.021**
Irrigation (Aw) vs. Control (Cw)[2]	0.122	0.472	0.107	0.082	0.657	0.661	0.066	0.250	**0.014**
Precipitation Reduced (Rw) vs. Cw	0.802	0.117	0.968	**0.013**	0.184	0.585	**0.002**	0.624	**0.013**
Aw vs. Rw	0.074	0.386	0.115	**0.000**	0.079	0.327	**0.000**	0.505	**0.000**

[1] Control (Cs) is no sward disturbance.

[2] Control (Cw) is no precipitation manipulation.

Table 16. Biomass for Junegrass and blue grama at anthesis for 3 precipitation treatments and 5 sward disturbances at Dundurn in 1997.

	Junegrass							blue grama						
	Sward disturbance													
Precipitation treatment	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]
	Inflorescences (g)													
Control	0.019	0.014	0.023	0.030	0.020	0.021		0.039	0.045	0.037	0.037	0.036	0.039	
Reduced	0.020	0.018	0.036	0.029	0.018	0.024		0.031	0.035	0.035	0.032	0.032	0.033	
Irrigation	0.017	0.019	0.026	0.027	0.025	0.023	0.002	0.041	0.050	0.047	0.034	0.041	0.042	0.001
Mean	0.018	0.017	0.028	0.029	0.021		0.002	0.037	0.043	0.040	0.034	0.036		0.002
	Culms (g)													
Control	0.049	0.045	0.071	0.089	0.059	0.062		0.052	0.064	0.047	0.045	0.049	0.051	
Reduced	0.052	0.053	0.048	0.080	0.045	0.055		0.040	0.046	0.049	0.046	0.048	0.046	
Irrigation	0.056	0.057	0.082	0.071	0.074	0.068	0.005	0.057	0.071	0.059	0.043	0.051	0.056	0.003
Mean	0.052	0.051	0.067	0.080	0.059		0.006	0.050	0.060	0.051	0.045	0.049		0.004
	Total (g)													
Control	0.068	0.059	0.094	0.094	0.079	0.079		0.091	0.109	0.084	0.082	0.085	0.090	
Reduced	0.071	0.071	0.110	0.116	0.063	0.086		0.071	0.081	0.084	0.078	0.079	0.079	
Irrigation	0.073	0.076	0.100	0.098	0.070	0.083	0.012	0.098	0.091	0.102	0.077	0.091	0.092	0.004
Mean	0.071	0.068	0.101	0.103	0.071		0.015	0.087	0.094	0.090	0.079	0.085		0.005

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[1] Within biomass components upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

Table 17. Biomass for Junegrass and blue grama at anthesis for 3 precipitation treatments and 5 sward disturbances at Rudy in 1998.

	Junegrass							blue grama						
	Sward treatment													
Precipitation Treatment	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]
	Inflorescence s (g)													
Control	0.085	0.098	0.080	0.080	0.099	0.088		0.113	0.113	0.163	0.180	0.093	0.132	
Reduced	0.068	0.092	0.057	0.071	0.068	0.071		0.083	0.100	0.113	0.130	0.078	0.101	
Irrigation	0.081	0.137	0.118	0.109	0.077	0.104	0.007	0.090	0.120	0.198	0.160	0.095	0.133	0.005
Mean	0.078	0.109	0.085	0.087	0.081		0.009	0.095	0.112	0.158	0.157	0.088		0.006
	Culms (g)													
Control	0.067	0.075	0.068	0.077	0.086	0.075		0.278	0.348	0.383	0.453	0.263	0.345	
Reduced	0.062	0.083	0.057	0.083	0.054	0.068		0.238	0.263	0.295	0.285	0.230	0.262	
Irrigation	0.066	0.083	0.092	0.094	0.067	0.080	0.005	0.293	0.378	0.488	0.465	0.260	0.377	0.015
Mean	0.065	0.080	0.072	0.085	0.069		0.006	0.269	0.335	0.388	0.401	0.251		0.020
	Total (g)													
Control	0.151	0.173	0.148	0.157	0.185	0.163		0.390	0.460	0.545	0.633	0.355	0.477	
Reduced	0.130	0.175	0.113	0.154	0.122	0.139		0.320	0.363	0.408	0.415	0.308	0.363	
Irrigation	0.147	0.219	0.210	0.203	0.144	0.185	0.011	0.383	0.498	0.685	0.625	0.355	0.509	0.018
Mean	0.143	0.189	0.157	0.171	0.150		0.014	0.364	0.447	0.546	0.558	0.339		0.024

[1] Within biomass components upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

At Rudy in 1998, total standing crop was greater after nitrogen application than after mechanical disturbance, but other sward disturbances had no effect on standing crop. Total standing crop and that of graminoids was greatest when irrigated, intermediate in control, and least when precipitation was reduced (Tables 14 and 15).

At Dundurn in 1998, standing crop of graminoids was greater where clubmoss was killed than in control (Tables 14 and 15). Mechanical disturbance and applying nitrogen increased standing crop of graminoids and forbs compared to control. Irrigating increased peak standing crop of graminoids compared to reducing precipitation and control.

Above-ground biomass in Junegrass and blue grama

Sward disturbances and precipitation treatments had variable effects on above-ground biomass allocation in Junegrass and blue grama (Tables 16-19). Interacting effects of sward disturbance and precipitation treatments were generally not significant ($P>0.05$) (Appendix A).

At Dundurn in 1997, weights of inflorescences, culms, and total above-ground biomass of Junegrass were not affected by killing or removing clubmoss (Tables 16 and 19). Compared to control, culm weights increased after adding nitrogen. Inflorescence and culm weights were heavier in the mechanical disturbance than when nitrogen was added. Reducing precipitation or irrigating had no effect on biomass of Junegrass relative to control; however, culms and inflorescences were heavier when irrigated than when precipitation was reduced. Inflorescences and total biomass of blue grama were heavier when clubmoss was killed compared to control (Tables 16 and 19). Total biomass and inflorescences were heavier after removing than killing clubmoss. Mechanical disturbance decreased weights of inflorescences, culms, and total biomass of blue grama relative to control and adding nitrogen, but weights were not different between the later 2 disturbances. Precipitation treatments had no effect on plant weights.

At Rudy in 1998, weights of inflorescences, culms and total biomass for Junegrass were not affected by killing or removing clubmoss (Tables 17 and 19). Adding nitrogen increased total biomass and weights of Junegrass inflorescences compared to control, and mechanically disturbing plots increased culm weights relative to control, but inflorescences were heavier with nitrogen added than when mechanically disturbed. Weights of blue grama were not affected by removing clubmoss relative to control, but inflorescences, culms and total biomass were lighter when clubmoss was removed than if killed. Blue grama inflorescences and total biomass were also lighter on control than plots with clubmoss killed. Adding nitrogen did not affect weight of blue grama, but mechanical disturbance increased weight of inflorescences, culms and total biomass compared to control, and inflorescences and total biomass were heavier relative to adding nitrogen (Tables 17 and 19).

Irrigation did not influence ($P>0.05$) weights of Junegrass or blue grama relative to control at Rudy in 1998 (Table 18 and 20). Reducing precipitation decreased weights of Junegrass inflorescences compared to control, and decreased weights of inflorescences, culms, and total biomass relative to irrigating. Reducing precipitation also reduced weights of blue grama inflorescences, culms and total biomass compared to the other precipitation treatments.

Table 18. Biomass for Junegrass and blue grama at anthesis for 3 precipitation treatments and 5 sward disturbances at Dundurn in 1998.

	Junegrass							blue grama						
	Sward disturbance													
Precipitation treatment	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]
	Inflorescences (g)													
Control	0.107	0.119	0.090	0.131	0.086	0.107		0.075	0.075	0.090	0.105	0.080	0.085	
Reduced	0.117	0.088	0.143	0.195	0.116	0.132		0.075	0.100	0.080	0.105	0.093	0.091	
Irrigation	0.122	0.104	0.150	0.152	0.119	0.129	0.010	0.090	0.080	0.098	0.093	0.075	0.087	0.010
Mean	0.115	0.103	0.128	0.159	0.107		0.012	0.080	0.085	0.089	0.102	0.082		0.012
	Culm (g)													
Control	0.081	0.093	0.087	0.109	0.078	0.089		0.193	0.238	0.253	0.358	0.263	0.261	
Reduced	0.101	0.101	0.109	0.166	0.095	0.114		0.225	0.240	0.233	0.278	0.260	0.246	
Irrigation	0.102	0.104	0.113	0.102	0.095	0.103	0.007	0.298	0.268	0.308	0.297	0.245	0.282	0.007
Mean	0.095	0.099	0.103	0.126	0.089		0.009	0.238	0.248	0.264	0.312	0.255		0.009
	Total (g)													
Control	0.188	0.211	0.177	0.239	0.164	0.196		0.268	0.313	0.343	0.463	0.343	0.346	
Reduced	0.218	0.188	0.252	0.361	0.211	0.246		0.300	0.340	0.313	0.383	0.353	0.337	
Irrigation	0.224	0.208	0.263	0.254	0.214	0.233	0.015	0.388	0.348	0.405	0.390	0.320	0.369	0.015
Mean	0.210	0.203	0.231	0.285	0.196		0.020	0.318	0.333	0.353	0.414	0.337		0.020

[1] Within biomass components upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

Table 19. Probabilities that contrasts of mean biomass allocation for Junegrass and blue grama at anthesis are different for 3 precipitation treatments and 5 sward disturbances at Dundurn in 1997. Bold values indicate means are different ($P \leq 0.05$).

	Biomass category					
	Junegrass			blue grama		
Treatment contrast	Inflorescence	Culms	Total	Inflorescence	Culms	Total
	Calculated probability					
	Dundurn 1997					
Control (Cs)[1] vs. Clubmoss removed (CR)	0.771	0.945	0.880	0.470	0.409	0.979
Clubmoss killed (K) vs. (CR)	0.317	0.617	0.603	**0.032**	0.364	**0.025**
Cs vs. K	0.475	0.666	0.711	**0.005**	0.087	**0.024**
Nitrogen (N) vs. Cs	0.100	**0.016**	0.447	0.669	0.938	0.874
Mechanical (M) vs. Cs	0.424	0.262	0.397	**0.003**	**0.002**	**0.018**
M vs. N	**0.017**	**0.001**	0.112	**0.001**	**0.002**	**0.012**
Irrigation (Aw) vs. Control (Cw)[2]	0.215	0.158	0.808	0.614	0.421	0.660
Precipitation Reduced (Rw) vs. Cw	0.052	0.081	0.108	0.256	0.296	0.469
Aw vs. Rw	**0.002**	**0.002**	0.066	0.523	0.068	0.775
	Rudy 1998					
Cs vs. CR	0.549	0.654	0.707	0.760	0.682	0.767
K vs. CR	0.732	0.708	0.707	**0.000**	**0.026**	**0.001**
Cs vs. K	0.524	0.332	0.411	**0.001**	0.052	**0.005**
N vs. Cs	**0.006**	0.052	**0.011**	0.672	0.524	0.454
M vs. Cs	0.411	**0.013**	0.104	**0.001**	**0.033**	**0.003**
M vs. N	**0.045**	0.556	0.322	**0.004**	0.125	**0.019**
Aw vs. Cw	0.057	0.359	0.115	0.971	0.493	0.493
Rw vs. Cw	**0.043**	0.249	0.079	**0.011**	**0.045**	**0.008**
Aw vs. Rw	**0.000**	**0.042**	**0.001**	**0.010**	**0.009**	**0.001**
	Dundurn 1998					
Cs vs. CR	0.628	0.700	0.648	0.586	0.892	0.808
K vs. CR	0.219	0.329	0.247	0.128	0.331	0.246
Cs vs. K	0.452	0.552	0.479	0.320	0.401	0.357
N vs. Cs	0.482	0.736	0.809	0.586	0.744	0.691
M vs. Cs	**0.011**	**0.028**	**0.014**	0.151	0.127	0.113
M vs. N	**0.002**	0.060	**0.007**	0.366	0.226	0.229
Aw vs.Cw	0.082	0.202	0.112	0.725	0.752	0.864
Rw vs. Cw	0.057	**0.034**	**0.032**	0.888	0.268	0.386
Aw vs. Rw	0.859	0.301	0.555	0.623	0.157	0.300

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[1] Control (Cs) is no sward disturbance.

[2] Control (Cw) is no precipitation manipulation.

Table 20. Phenological stages of development for Junegrass and blue grama on 6 dates for 3 precipitation treatments and 5 sward disturbances at Dundurn in 1997.

			Sward disturbance						
Precipitation treatment	Species	Date	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]
			Moore's index (leaf development)						
Control	Junegrass	May 15	1.1	1.1	1.0	1.0	1.1	1.1	
Reduced			1.1	1.2	1.1	1.0	1.1	1.1	
Irrigation			1.1	1.2	1.0	1.1	1.1	1.1	0.01
Mean			1.1	1.1	1.0	1.0	1.1		0.02
Control		23	1.2	1.1	1.1	1.1	1.1	1.1	
Reduced			1.1	1.1	1.1	1.1	1.1	1.1	
Irrigation			1.2	1.2	1.1	1.0	1.1	1.1	0.01
Mean			1.1	1.1	1.1	1.0	1.1		0.02
Control		Jun. 11	2.8	2.6	2.0	2.5	2.3	2.4	
Reduced			2.8	2.6	2.6	2.3	2.0	2.4	
Irrigation			2.4	2.6	2.4	2.2	2.3	2.4	0.10
Mean			2.6	2.6	2.3	2.3	2.2		0.13
Control	blue grama	28	1.7	1.6	1.8	1.8	1.7	1.7	
Reduced			1.4	1.5	1.7	1.7	1.4	1.5	
Irrigation			1.7	1.7	1.7	1.7	1.7	1.7	0.03
Mean			1.6	1.6	1.7	1.7	1.6		0.04
Control		Jul. 11	2.8	2.1	3.3	3.3	3.3	2.9	
Reduced			1.9	2.4	2.6	3.2	1.8	2.4	
Irrigation			2.5	2.8	3.3	3.0	3.0	2.9	0.18
Mean			2.4	2.4	3.0	3.2	2.7		0.23
Control		30	3.5	3.5	3.5	3.5	3.5	3.5	
Reduced			3.5	3.4	3.5	3.5	3.5	3.5	
Irrigation			3.5	3.5	3.5	3.5	3.4	3.5	0.02
Mean			3.5	3.5	3.5	3.5	3.5		0.03

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[1] Within dates upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

At Dundurn in 1998, killing or removing clubmoss did not alter ($P>0.05$) weights of inflorescences, culms, or total biomass of Junegrass or blue grama while adding nitrogen had no influence on weights relative to control (Tables 18 and 19). Mechanical disturbance increased weights of Junegrass inflorescences, culms and total biomass compared to control, and weights of inflorescences and total biomass were greater after mechanical disturbance than with nitrogen added. Irrigation had no effect on weights of Junegrass or blue grama compared to control or reducing precipitation. Reducing precipitation, however, decreased weight of culms and total biomass relative to control (Tables 18 and 19).

Phenological development of Junegrass and blue grama

Mechanical disturbance, adding nitrogen, and killing or removing clubmoss had no consistent effect on phenology of Junegrass or blue grama on most dates at Dundurn in 1997 and 1998, and at Rudy in 1998 (Tables 20-23). Irrigating or reducing precipitation did not affect phenological development of Junegrass and blue grama on most dates at Dundurn in 1997 and Rudy in 1998; however, Junegrass and blue grama developed faster when precipitation was reduced at Dundurn in 1998. Interacting effects of sward disturbances and precipitation treatments on phenology of Junegrass and blue grama were not significant ($P>0.05$) in most cases (Appendix A).

Soil nitrogen supply rate

Generally, nitrogen supply rate was not affected ($P>0.05$) by sward disturbance, precipitation treatments (Tables 24 and 25), or their interaction (Appendix A). Exceptions occurred at Dundurn in 1997 when the nitrogen supply rate was higher following mechanical disturbance than in control or when nitrogen was added. Other exceptions occurred in 1998 at Rudy when the nitrogen supply rate was higher when clubmoss was killed relative to clubmoss removal and control. Reducing precipitation, however, decreased the nitrogen supply rate compared to irrigation and control.

Effects of simulated precipitation events and clubmoss on soil water and mid-day leaf xylem water potentials in Junegrass and blue grama

With few exceptions, soil water and leaf xylem water potentials in 1997 (Tables 26 to 31) and 1998 (Tables 32 to 38) were not affected ($P>0.05$) by clubmoss. Soil water, at 0-3 and 3-30 cm depths, and leaf xylem water potentials usually increased when precipitation increased was added compared to control. Clubmoss did not affect soil water or leaf xylem water potentials.

As expected, soil water and leaf xylem water potentials increased to varying degrees when irrigated (Appendix B). Regardless of whether clubmoss was present or not, soil water and leaf xylem water potentials increased as irrigation increased. Precipitation effects on soil water and leaf xylem water potentials usually persisted longer as the amount of irrigation increased; however, clubmoss had no influence on soil water and leaf xylem water potentials.

Table 21. Phenological stages of Junegrass and blue grama on 6 dates for 3 precipitation treatments and 5 sward disturbances at Rudy in 1998.

Precipitation Treatment	Species	Date	Sward disturbance						
			Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]
			Moore's index (leaf development)						
Control	Junegrass	May 6	1.73	1.52	1.52	1.48	1.52	1.55	
Reduced			1.65	1.48	1.52	1.44	1.48	1.51	
Irrigation			1.48	1.52	1.61	1.44	1.48	1.51	0.09
Mean			1.62	1.51	1.55	1.45	1.49		0.12
Control		Jun. 4	3.03	3.10	2.92	3.20	3.18	3.08	
Reduced			3.12	3.18	3.03	3.25	3.15	3.14	
Irrigation			3.30	3.10	3.15	3.30	3.30	3.23	0.03
Mean			3.15	3.13	3.03	3.25	3.21		0.04
Control		23	3.90	3.90	3.85	3.90	3.90	3.89	
Reduced			3.90	3.90	3.90	3.90	3.90	3.90	
Irrigation			3.90	3.90	3.90	3.90	3.90	3.90	0.01
Mean			3.90	3.90	3.88	3.90	3.90		0.01
Control	blue grama	23	2.17	2.06	2.17	2.26	2.00	2.13	
Reduced			2.06	2.06	2.40	2.31	2.00	2.16	
Irrigation			2.31	2.31	2.48	2.48	2.12	2.34	0.03
Mean			2.18	2.14	2.35	2.35	2.04		0.04
Control		Jul. 13	3.08	3.03	3.45	3.40	3.10	3.21	
Reduced			3.10	2.95	3.20	3.45	3.13	3.17	
Irrigation			3.20	3.40	3.50	3.35	3.30	3.35	0.05
Mean			3.13	3.13	3.38	3.40	3.18		0.07
Control		27	3.45	3.48	3.65	3.65	3.60	3.57	
Reduced			3.55	3.55	3.65	3.65	3.55	3.59	
Irrigation			3.55	3.40	3.60	3.65	3.55	3.55	0.02
Mean			3.52	3.48	3.63	3.65	3.57		0.03

[1] Within dates upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

Table 22. Phenological stages of Junegrass and blue grama on 6 dates for 3 precipitation amounts and 5 sward disturbances at Dundurn in 1998.

			Sward disturbance						
precipitation treatment	Species	Date	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]
			Moore's index (leaf development)						
Control	Junegrass	May 6	1.61	1.61	1.52	1.48	1.73	1.59	
Reduced			1.48	1.52	1.52	1.78	1.50	1.56	
Irrigation			1.44	1.61	1.61	1.52	1.52	1.54	0.05
Mean			1.51	1.58	1.55	1.59	1.58		0.07
Control		Jun. 4	3.20	3.10	3.20	3.20	3.25	3.19	
Reduced			3.25	3.25	3.25	3.30	3.25	3.26	
Irrigation			3.25	3.30	3.30	3.35	3.40	3.32	0.16
Mean			3.23	3.22	3.25	3.28	3.30		0.21
Control		23	3.90	3.90	3.90	3.90	3.85	3.89	
Reduced			3.85	3.90	3.80	3.40	3.32	3.65	
Irrigation			3.32	3.28	3.22	3.32	3.23	3.27	0.20
Mean			3.69	3.69	3.64	3.54	3.46		0.25
Control	blue grama	23	2.23	2.00	2.06	2.17	2.06	2.10	
Reduced			2.20	2.31	2.65	2.52	2.26	2.39	
Irrigation			2.48	2.26	2.51	2.49	2.00	2.34	0.20
Mean			2.30	2.19	2.40	2.39	2.10		0.26
Control		Jul. 13	2.82	2.82	2.99	3.10	2.78	2.90	
Reduced			3.30	3.15	3.20	3.25	3.03	3.19	
Irrigation			2.95	3.02	3.10	3.37	3.08	3.09	0.04
Mean			3.02	2.99	3.10	3.23	2.96		0.05
Control		27	3.45	3.55	3.60	3.60	3.65	3.57	
Reduced			3.60	3.60	3.65	3.65	3.65	3.63	
Irrigation			3.55	3.60	3.50	3.70	3.60	3.58	0.02
Mean			3.53	3.58	3.58	3.65	3.63		0.03

[1] Within dates upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

Table 23. Probabilities that contrasts of mean phenological stages of Junegrass and blue grama are different on 6 dates for 3 precipitation amounts and 5 sward disturbances at Dundurn in 1997. Bold values indicate means are different ($P \leq 0.05$).

			Junegrass			blue grama		
			Date of determination					
			May		Jun.		Jul.	
Treatment contrast	Site	Year	15	23	11	28	11	30
			Calculated probability					
Control (Cs)[1] vs. Clubmoss removed (CR)	Dundurn	1997	0.650	0.252	**0.022**	0.922	0.128	0.604
Clubmoss killed (K) vs. (CR)			0.178	0.444	0.600	0.148	0.110	1.000
Cs vs. K			0.075	0.060	0.072	0.176	**0.003**	0.604
Nitrogen (N) vs. Cs			0.178	0.701	0.827	1.000	0.871	0.302
Mechanical (M) vs. Cs			0.075	**0.025**	0.111	0.124	**0.000**	0.604
M vs. N			**0.003**	0.060	0.166	0.124	**0.001**	0.604
Irrigation (Aw) vs. Control (Cw)[2]			0.725	0.766	0.636	0.546	0.802	1.000
Precipitation Reduced (Rw) vs. Cw			0.295	0.766	0.919	**0.009**	**0.001**	0.423
Aw vs. Rw			0.483	1.000	0.565	**0.039**	**0.001**	0.423
Cs vs. CR	Rudy	1998	**0.006**	0.321	1.000	**0.024**	0.801	0.794
K vs. CR			0.214	**0.006**	0.121	**0.000**	0.297	0.728
Cs vs. K			0.116	0.064	0.121	**0.008**	0.197	0.543
N vs. Cs			**0.014**	0.726	1.000	0.531	1.000	0.828
M vs. Cs			**0.000**	0.100	1.000	**0.008**	0.170	0.488
M vs. N			0.228	0.048	1.000	**0.002**	0.170	0.363
Aw vs. Cw			0.154	**0.004**	0.228	**0.000**	0.365	0.919
Rw vs. Cw			0.232	0.214	0.228	0.486	0.770	0.866
Aw vs. Rw			0.814	0.074	1.000	0.001	0.233	0.788
Cs vs. CR	Dundurn		**0.002**	0.079	0.372	0.077	0.544	0.138
K vs. CR			0.116	0.185	0.487	**0.009**	0.182	0.454
Cs vs. K			0.081	0.655	0.842	0.362	0.461	0.454
N vs. Cs			**0.004**	0.655	0.989	0.306	0.780	0.454
M vs. Cs			**0.001**	0.185	0.551	0.296	0.533	**0.006**
M vs. N			0.506	0.079	0.542	0.982	0.730	**0.001**
Aw vs. Control Cw			**0.006**	**0.000**	**0.003**	0.173	0.675	**0.003**
Rw vs. Cw			0.107	**0.019**	**0.227**	**0.002**	**0.001**	0.248
Aw vs. Rw			0.221	**0.043**	0.053	0.057	**0.002**	**0.000**

[1] Control (Cs) is no sward disturbance.

[2] Control (Cw) is no precipitation manipulation.

Table 24. Soil nitrogen (NO_3) in the 0-30 cm depth of the profile for 3 precipitation treatments and 5 sward disturbances at Dundurn in 1997 and at Dundurn and Rudy in 1998.

			Sward disturbance						
Precipitation treatment	**Study site**	**Year**	**Control**	**Nitroge added**	**Clubmoss killed**	**Mechanical**	**Clubmoss removed**	**Mean**	**Standard error**
			Soil nitrogen ($\mu g\ cm^{-2}$ 2 $weeks^{-1}$)						
Control	Dundurn	1997	56.2	9.7	6.1	74.6	18.4	33.0	
Reduced			15.2	26.6	20.6	144.2	19.7	45.3	
Irrigation			2.4	0.7	2.0	47.6	57.4	22.0	11.21
Mean			24.6	12.3	9.6	88.8	31.8		14.27
Control		1998	2.7	5.8	34.6	32.5	7.9	16.7	
Reduced			4.3	42.3	8.3	14.7	4.3	14.8	
Irrigation			5.1	1.0	0.2	5.7	0.5	2.4	4.15
Mean			4.0	17.8	14.4	18.7	4.3		5.36
Control	Rudy	1998	13.3	5.7	57.7	22.7	13.5	22.6	
Reduced			1.0	4.4	3.8	2.2	3.9	3.1	
Irrigation			11.5	18.2	40.7	32.4	25.1	25.6	6.06
Mean			8.6	9.4	34.1	21.2	14.2		7.38

[1] Within season of growth the upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

[2] See methods and materials for description of units.

Table 25. Probabilities that contrasts for mean soil nitrogen (NO_3) in the 0-30 cm depth of the profile are different at Dundurn in 1997 and at Dundurn and Rudy in 1998. Bold values indicate means are different ($P<0.05$).

	Dundurn		Rudy
Treatment contrast	1997	1998	1997
	Calculated probability		
Control (Cs)[1] vs. Clubmoss removed (CR)	0.804	0.985	0.536
Clubmoss killed (K) vs. (CR)	0.445	0.362	**0.033**
Cs vs. K	0.605	0.352	**0.008**
Nitrogen (N) vs. Cs	0.673	0.271	0.926
Mechanical (M) vs. Cs	0.034	0.239	0.257
M vs. N	**0.013**	0.937	0.297
Irrigation (Aw) vs. Control (Cw)[2]	0.625	0.095	0.669
Precipitation Reduced (Rw) vs. Cw	0.586	0.824	**0.008**
Aw vs. Rw	0.305	0.145	**0.003**

Table 26. Soil water at the 0-3 cm depth of the profile on 4 days following addition of 0-25 mm of water to plots in which clubmoss was present or removed in May and June 1997.

		May									June								
		Water added (mm)																	
Day	Clubmoss treatment	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]
		Soil water (%)																	
0[2]	Removed	31.2	20.8	21.5	32.6	25.7	24.6	28.3	26.4		18.1	12.8	15.1	20.5	12.6	9.8	14.8	14.8	
	Present	34.1	30.4	33.8	24.6	28.4	31.0	32.4	30.7	18.81	6.3	15.5	13.3	20.6	7.8	16.3	28.5	15.5	
	mean	32.6	25.6	27.6	28.6	27.0	27.8	30.4		2.65	12.2	14.1	14.2	20.6	10.2	13.0	21.7		29.85
																			3.34
1	Removed	–[3]	–	–	– –	–	–	–	–		18.9	16.6	16.2	16.0	18.7	18.2	17.5	17.4	
	Present	–	–	–	–	–	–	–	–		10.5	20.7	15.5	26.5	13.2	20.5	22.7	18.5	18.69
	mean	–	–	–	–	–	–	–	–		14.7	18.7	15.8	21.3	15.9	19.4	20.1		2.64
2	Removed	25.8	22.1	28.4	29.1	26.2	23.0	29.8	26.4		18.4	17.9	13.2	20.5	20.1	15.6	21.6	18.6	
	Present	29.1	27.1	29.4	27.4	25.9	30.1	26.9	28.0	5.70	11.8	18.7	13.0	22.7	16.9	18.8	22.2	17.7	5.49
	mean	27.4	24.9	28.9	28.3	26.0	26.5	28.3		1.46	15.1	18.3	14.6	21.6	18.5	17.2	21.9		1.43
4	Removed	23.7	21.4	25.0	23.0	23.8	22.6	24.5	23.4		15.9	21.2	16.0	16.6	14.2	15.6	14.1	16.2	
	Present	25.6	18.6	22.6	25.8	25.0	31.4	21.2	24.3	8.09	7.8	12.6	13.6	21.2	11.0	18.2	19.7	14.9	15.10
	mean	24.6	20.0	23.8	24.4	24.4	27.0	22.8		1.74	11.8	16.9	14.8	18.9	12.6	16.9	16.9		2.37
7	Removed	20.6	13.7	15.0	17.5	13.2	16.2	15.6	16.0		13.1	14.6	13.5	13.5	12.1	9.6	11.6	12.6	
	Present	19.6	12.1	13.1	14.3	16.3	15.0	14.1	14.9	1.75	7.8	9.8	10.3	17.7	10.0	13.2	15.3	12.0	8.07
	mean	20.1	12.9	14.0	15.9	14.7	15.6	14.8		0.81	10.5	12.2	11.9	15.6	11.0	11.4	13.5		1.73

[1] Within days the upper value is standard error for water treatments and lower value is standard error for sward disturbance.

[2] Pre water treatment.

[3] Data missing

Table 27. Soil water at the 0-3 cm depth of the profile on 4 days following addition of 0-25 mm of water to plots in which clubmoss was present or removed in July 1997.

		Water added (mm)								
Day	Clubmoss treatment	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]
		Soil water (%)								
0[2]	Removed	8.3	2.6	2.6	2.7	2.6	2.8	1.7	3.3	
	Present	2.8	3.8	3.0	2.6	2.7	2.5	3.0	2.9	0.12
	mean	5.6	3.2	2.8	2.6	2.6	2.7	2.4		0.21
1	Removed	2.2	2.3	2.3	3.5	4.3	4.4	4.5	3.3	
	Present	2.9	2.4	2.5	3.6	3.2	3.6	6.5	3.5	0.36
	mean	2.6	2.3	2.4	3.6	3.7	4.0	5.5		0.37
2	Removed	2.3	2.9	2.8	4.9	6.1	5.8	5.3	4.3	
	Present	2.9	2.6	2.7	3.7	4.1	6.3	6.9	4.2	2.52
	mean	2.6	2.7	2.7	4.3	5.1	6.0	6.1		0.97
4	Removed	2.3	2.5	2.6	3.2	4.4	6.3	4.6	3.7	
	Present	2.9	2.5	2.5	4.1	4.2	4.9	4.6	3.6	2.64
	mean	2.6	2.5	2.5	3.6	4.3	5.6	4.6		0.99
7	Removed	2.1	2.1	2.5	2.7	3.7	4.3	3.6	3.0	
	Present	2.2	2.2	2.3	3.2	3.4	4.1	3.5	3.0	0.74
	mean	2.2	2.1	2.4	3.0	3.5	4.2	3.5		0.53

[1] Within days the upper value is standard error for water treatments and lower value is standard error for sward disturbance.

[2] Pre-water treatment.

Table 28. Soil water at the 3-30 cm depth of the profile on 4 days following addition of 0-25 mm of water to plots in which clubmoss was present or removed in May and June 1997.

		May									June								
		Water added (mm)																	
Day	Clubmoss treatment	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]
		Soil water (%)																	
0[2]	Removed	9.7	7.5	8.1	8.7	8.2	8.4	8.0	8.4		7.1	6.7	5.7	7.8	5.9	3.3	4.7	5.9	
	Present	10.1	8.3	8.2	8.2	8.6	7.6	8.8	8.5	0.18	3.4	6.2	6.0	8.6	4.5	6.8	7.4	6.1	2.69
	mean	9.9	7.9	8.1	8.4	8.4	8.0	8.4		0.26	5.2	6.5	5.9	8.2	5.2	5.1	6.1		1.00
1	Removed	10.1	8.6	9.0	10.0	8.8	9.6	8.9	9.3		7.2	6.1	5.6	7.8	7.4	4.6	6.9	6.5	
	Present	10.0	9.0	8.8	9.0	8.7	9.0	8.6	9.1	0.13	4.0	6.8	6.0	9.1	5.5	7.6	8.4	6.7	1.98
	mean	10.0	8.8	8.9	9.5	8.7	9.3	9.3		0.22	5.6	6.5	5.8	8.4	6.4	6.1	7.6		0.86
2	Removed	3.0	7.4	8.7	8.5	8.1	9.0	8.6	8.5		7.9	6.4	5.9	7.1	6.8	5.0	6.6	6.5	
	Present	9.6	8.8	7.6	9.0	8.8	8.5	9.5	8.8	0.31	3.9	6.8	6.3	8.3	8.5	6.5	7.8	6.8	1.74
	mean	9.3	8.1	8.1	8.7	8.4	8.8	9.0		0.34	5.9	6.6	6.1	7.7	7.6	5.7	7.2		0.81
4	Removed	9.0	7.1	7.6	8.0	7.4	8.3	8.1	7.9		6.1	5.9	5.5	6.6	5.9	5.0	5.3	5.8	
	Present	8.5	7.5	7.6	8.1	7.7	8.5	8.1	8.0	0.04	3.6	5.4	7.1	7.3	4.7	5.9	6.4	5.8	1.00
	mean	8.8	7.3	7.6	8.0	8.5	8.4	8.1		0.12	4.9	5.7	6.3	6.9	8.3	5.4	5.9		0.61
7	Removed	7.3	7.0	6.9	7.2	6.7	7.1	6.6	7.0		6.1	6.3	5.4	6.2	5.5	3.9	5.8	5.6	
	Present	6.6	5.0	5.9	6.3	7.6	6.6	6.6	6.4	0.34	3.5	4.9	5.3	6.5	4.9	5.5	5.9	5.2	0.81
	mean	6.9	6.0	6.4	6.7	7.2	6.9	6.6		0.36	4.7	5.6	5.3	6.3	5.2	4.7	5.9		0.55

[1] Within days the upper value is standard error for water treatments and lower value is standard error for sward disturbance.

[2] Pre-water treatment.

Table 29. Soil water at the 3-30 cm depth of the profile on 4 days following addition of 0-25 mm of water on plots in which clubmoss was present or removed in July 1997.

		Water added (mm)								
Day	Clubmoss treatment	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]
		Soil water (%)								
0[2]	Removed	8.3	2.6	2.6	2.7	2.6	2.8	1.7	3.3	
	Present	2.8	3.8	3.0	2.6	2.7	2.5	3.0	2.9	2.40
	mean	5.6	3.2	2.8	2.6	2.6	2.7	2.4		0.95
1	Removed	2.2	2.3	2.3	3.5	4.3	4.4	4.5	3.3	
	Present	2.9	2.4	2.5	3.6	3.2	3.6	6.5	3.5	0.49
	mean	2.6	2.3	2.4	3.6	3.7	4.0	5.5		0.43
2	Removed	2.3	2.9	2.8	4.9	6.1	5.8	5.3	4.3	
	Present	2.9	2.6	2.7	3.7	4.1	6.3	6.9	4.2	0.66
	mean	2.6	2.7	2.7	4.3	5.1	6.0	6.1		0.49
4	Removed	2.3	2.5	2.6	3.2	4.4	6.3	4.6	3.7	
	Present	2.9	2.5	2.5	4.1	4.2	4.9	4.6	3.6	0.23
	mean	2.6	2.5	2.5	3.6	4.3	5.6	4.6		0.29
7	Removed	2.1	2.1	2.5	2.7	3.7	4.3	3.6	3.0	
	Present	2.2	2.2	2.3	3.2	3.4	4.1	3.5	3.0	0.04
	mean	2.2	2.1	2.4	3.0	3.5	4.2	3.5		0.12

[1] Within days the upper value is standard error for water treatments and lower value is standard error for sward disturbance.

[2] Pre-water treatment.

Table 30. Mid-day leaf xylem water potentials on 4 days for Junegrass in May and June and for blue grama in July in 1997 following addition of 0-25 mm of water on plots with clubmoss present or removed.

		Junegrass																		Blue grama								
		May									Jun.									Jul.								
		Water added (mm)																										
Day	Clubmoss treatment	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]
		Leaf xylem water potential (-MPa)																										
0[2]	Removed	1.8	1.5	1.9	1.9	1.7	1.9	1.8	2.2		2.0	2.1	1.9	1.8	1.8	2.0	2.2	2.0		4.2	4.1	4.3	3.8	4.2	4.1	4.4	4.2	
	Present	1.7	2.2	1.7	1.8	1.7	1.6	1.6	3.3	0.05	2.1	2.1	2.0	2.0	2.3	2.2	2.2	2.1	0.02	3.9	4.3	4.0	4.3	4.2	4.0	4.2	4.1	0.04
	Mean	1.8	1.8	1.8	1.8	1.7	1.7	1.7		0.14	2.0	2.1	1.9	1.9	2.1	2.1	2.2		0.08	4.0	4.2	4.2	4.0	4.2	4.0	4.3		0.13
1	Removed	2.7	2.0	2.3	2.1	1.9	2.3	2.2	2.2		1.8	1.6	1.7	1.6	2.2	1.6	1.6	1.7		4.4	4.3	2.9	2.2	2.7	1.6	2.1	2.8	
	Present	2.0	2.6	2.5	2.1	2.2	2.5	2.4	2.3	0.07	2.1	1.9	1.7	1.5	1.9	1.8	1.9	2.8	0.03	4.6	3.5	4.0	2.4	1.9	1.8	1.9	2.7	0.09
	Mean	2.4	2.3	2.4	2.1	2.1	2.4	2.3		0.16	2.0	1.7	1.7	1.6	2.1	1.7	1.7		0.11	4.6	3.1	3.0	2.3	2.1	2.1	2.0		0.19
2	Removed	2.1	2.5	1.9	1.3	2.8	1.7	2.2	2.2		2.5	2.3	2.0	2.6	2.2	1.7	2.2	2.2		4.4	4.3	2.9	2.2	2.7	1.6	2.1	2.9	
	Present	1.8	2.1	2.1	2.1	2.0	1.8	2.2	2.0	0.05	1.8	2.1	1.7	1.9	2.0	1.1	2.1	1.9	0.06	4.6	3.5	4.0	2.4	1.9	1.8	1.9	2.9	0.21
	Mean	1.9	2.3	2.0	2.2	2.4	1.8	2.2		0.14	2.1	2.2	1.9	2.3	2.1	1.9	2.1		0.15	4.5	3.9	3.4	2.3	2.3	1.7	2.0		0.28
4	Removed	2.1	1.7	2.2	2.0	2.4	1.9	2.3	2.1		2.2	2.3	2.3	2.3	2.4	1.9	2.1	2.2		3.4	2.9	2.6	1.8	1.1	1.6	1.6	2.1	
	Present	2.2	2.8	2.1	1.8	2.2	2.1	2.2	2.2	0.09	2.0	2.0	1.9	2.1	2.2	2.3	2.2	2.1	0.03	2.4	3.5	1.9	1.9	1.4	1.1	0.8	1.8	0.17
	Mean	2.2	2.3	2.1	1.9	2.3	2.0	2.2		0.18	2.1	2.1	2.1	2.2	2.3	2.1	2.1		0.10	2.9	3.2	2.2	1.8	1.3	1.3	1.2		0.25
7	Removed	2.9	2.5	2.6	2.2	2.1	2.5	2.9	2.5		0.9	1.0	1.0	0.6	0.9	1.2	0.9	0.9		3.2	3.6	3.6	3.5	2.7	2.0	2.8	3.0	
	Present	2.6	2.7	2.3	2.8	2.7	2.1	2.8	2.6	0.09	1.2	1.3	1.0	0.6	1.2	1.0	0.8	1.0	0.02	3.0	3.1	3.0	2.5	3.1	2.7	3.0	2.9	0.15
	Mean	2.7	2.6	2.4	2.5	2.4	2.3	2.8		0.18	1.0	1.1	1.0	0.6	1.1	1.1	0.8		0.09	3.	3.	3.	3.0	2.9	2.3	2.9		0.24

[1] Within days the upper value is standard error for water treatments and lower value is standard error for sward disturbance.

[2] Pre-water treatment.

Table 31. Probabilities that contrasts of mean soil water in the 0-3 cm and 3-30 cm depth of the profile and mid-day leaf xylem water potentials are different on 4 days in plots with clubmoss present or removed following addition of 0-25 mm of water in 3 months in 1997. Bold values indicate contrasts are significantly different ($P \leq 0.05$).

Water added	Independent	May					Jun.					Jul.				
		Day														
(mm)	variable	0^1	1	2	4	7	0^1	1	2	4	7	0^1	1	2	4	7
		Calculated probability														
0.0	Soil water	0.559	**0.040**	0.370	0.664	0.732	0.117	0.104	0.138	0.200	0.308	0.090	0.897	0.831	0.783	0.935
2.5	(0-3 cm)	0.062	**0.044**	0.241	0.535	0.583	0.716	0.417	0.868	0.173	0.360	0.711	0.622	0.713	0.742	0.683
5.0		**0.018**	0.076	0.786	0.594	0.538	0.814	0.890	0.464	0.709	0.535	0.144	0.519	0.483	0.948	0.285
10.0		0.119	0.261	0.636	0.531	0.272	0.989	**0.044**	0.610	0.465	0.417	0.688	0.934	0.987	0.591	0.363
15.0		0.596	0.374	0.935	0.800	0.294	0.513	0.287	0.471	0.606	0.675	0.622	0.981	0.762	0.428	0.625
20.0		0.210	0.645	0.062	0.060	0.685	0.387	0.657	0.468	0.668	0.495	0.877	0.573	0.176	0.770	0.769
25.0		0.418	0.139	0.422	0.479	0.624	0.071	0.307	0.886	0.367	0.474	0.778	0.198	0.293	0.180	0.568
0.0	Soil water	0.657	0.919	0.473	0.459	0.280	0.117	0.065	**0.015**	0.413	0.123	0.018	**0.346**	0.405	0.388	0.859
2.5	(3-30 cm)	0.361	0.724	0.060	0.529	**0.005**	0.833	0.702	0.813	0.878	0.398	0.599	0.884	0.716	0.942	0.894
5.0		0.882	0.781	0.155	1.000	0.170	0.899	0.837	0.825	0.612	0.976	0.858	0.743	0.827	0.914	0.757
10.0		0.535	0.352	0.494	0.911	0.220	0.752	0.472	0.460	0.809	0.846	0.955	0.942	0.087	0.224	0.333
15.0		0.636	0.919	0.357	0.630	0.182	0.563	0.261	0.293	0.699	0.743	0.973	0.106	**0.005**	0.829	0.508
20.0		0.317	0.562	0.538	0.795	0.477	0.146	**0.091**	0.338	0.753	0.351	0.893	0.206	0.468	**0.049**	0.757
25.0		0.346	0.512	0.234	0.941	0.970	0.263	0.372	0.479	0.723	0.952	**0.005**	**0.020**	0.971	0.825	0.210
0.0	Mid-day leaf xylem	0.601	**0.050**	0.500	0.757	0.303	0.681	0.289	0.072	0.599	0.362	0.359	0.413	0.608	0.126	0.725
2.5	water potentials	**0.015**	0.105	0.426	**0.001**	0.632	0.837	0.447	0.587	0.499	0.403	0.623	0.441	0.095	0.354	0.483
5.0		0.542	0.617	0.712	0.816	0.474	0.538	0.939	0.456	0.205	0.939	0.392	0.291	**0.022**	0.281	0.371
10.0		0.663	0.943	0.581	0.699	0.051	0.538	0.647	0.054	0.548	0.939	0.247	0.664	0.681	0.877	0.133
15.0		1.000	0.319	**0.048**	0.589	0.072	**0.028**	0.289	0.542	0.652	0.362	0.902	0.250	0.106	0.614	0.533
20.0		0.385	0.720	0.806	0.537	0.135	0.608	0.493	0.379	0.233	0.493	0.759	0.499	0.758	0.462	0.295
25.0		0.385	0.433	0.854	0.643	0.632	0.918	0.403	0.892	0.880	0.703	0.540	0.530	0.608	0.219	0.755

[1] Pre-water treatment.

Table 32. Soil water at the 0-3 cm depth of the profile on 4 days following addition of 0-25 mm of water on plots in which clubmoss was present or removed in May and June 1998.

		May									Jun.								
		Water added (mm)																	
Day	Clubmoss treatment	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]
		(%)																	
0[2]	Removed	11.8	7.8	11.4	11.4	9.6	11.4	12.2	10.8		5.2	4.1	6.0	4.6	5.2	4.6	3.2	4.7	
	Present	11.5	11.4	10.7	10.4	10.2	10.3	9.6	10.6	1.63	2.9	3.4	3.2	4.5	4.0	2.7	4.3	3.6	0.81
	Mean	11.6	9.6	11.1	10.9	9.9	10.8	10.9		0.78	4.1	3.7	4.6	4.6	4.6	3.7	3.7		0.55
1	Removed	13.1	14.1	19.4	22.7	23.8	27.2	27.0	21.0		6.4	8.1	17.2	11.9	23.9	17.0	21.2	15.1	
	Present	9.9	15.3	23.5	21.4	22.7	29.6	25.6	21.1	2.89	3.1	5.5	8.6	15.8	18.9	19.3	18.4	12.8	8.07
	Mean	11.5	14.7	21.5	22.0	23.2	28.4	26.3		1.04	4.7	6.8	12.9	13.9	21..4	18.1	19.8		1.73
2	Removed	11.8	9.9	16.6	16.2	22.5	27.4	27.6	18.9		7.4	6.4	9.4	13.3	16.2	17.7	17.0	12.5	
	Present	9.2	9.7	19.8	21.3	21.0	24.9	26.4	18.9	3.95	3.4	5.6	7.5	14.9	16.6	15.2	14.7	11.1	1.55
	Mean	10.5	10.0	18.2	18.8	21.7	26.1	27.0		1.21	5.7	6.0	8.5	14.1	16.3	16.4	15.9		0.76
4	Removed	10.8	9.4	15.1	15.0	16.8	21.7	23.6	16.0		2.4	3.0	5.7	6.9	6.0	5.9	3.4	4.7	
	Present	11.4	16.0	16.9	16.2	17.1	21.1	17.8	16.7	5.92	3.1	4.5	4.5	7.1	6.2	5.8	6.7	5.4	0.89
	Mean	11.1	12.7	16.0	15.6	16.9	21.4	20.7		1.49	2.7	3.8	5.1	7.0	6.1	5.8	5.0		0.58
7	Removed	7.8	8.1	14.1	11.6	11.9	16.5	18.0	12.6		4.2	3.3	3.5	4.8	5.8	5.8	6.1	4.8	
	Present	6.2	11.6	11.9	15.7	12.7	15.8	13.6	12.5	4.16	2.9	3.4	3.6	4.5	6.3	6.6	8.1	5.0	0.48
	Mean	7.0	9.9	13.0	13.7	12.3	16.1	15.8		1.25	3.5	3.3	3.6	4.7	6.0	6.2	7.1		0.42

[1] Within days the upper value is standard error for water treatments and lower value is standard error for sward disturbance.

[2] Pre-water treatment.

Table 33. Soil water at the 0-3 cm depth of the profile on 4 days following addition of 0-25 mm of water on plots in which clubmoss was present or removed in July and August 1998.

		Jul.									Aug.								
		Water added (mm)																	
Day	Clubmoss treatment	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]
		(%)																	
0[2]	Removed	25.2	29.3	26.4	29.3	30.3	34.9	25.4	28.7		2.7	2.9	2.7	2.5	2.6	2.4	2.3	2.6	
	Present	22.7	31.8	29.7	29.9	39.9	31.0	28.5	30.5	6.61	2.0	2.0	2.8	2.3	2.2	1.9	2.3	2.2	0.06
	Mean	23.9	30.5	28.0	29.6	35.1	32.9	27.0		1.57	2.3	2.5	2.7	2.4	2.4	2.1	2.3		0.15
1	Removed	27.1	27.8	31.0	34.7	35.2	35.0	33.6	32.1		3.2	9.2	9.6	19.2	19.2	20.4	23.3	15.1	
	Present	26.1	35.9	27.2	29.3	39.8	36.5	33.9	32.7	7.29	7.7	6.4	15.1	15.2	21.4	21.0	25.2	16.7	4.99
	Mean	26.6	31.8	29.1	32.0	37.5	35.8	33.8		1.65	5.5	8.0	12.4	17.5	20.3	20.7	24.2		1.36
2	Removed	21.5	29.4	26.8	26.8	27.2	30.0	22.9	26.4		3.9	4.8	7.5	14.5	14.6	18.0	18.3	11.7	
	Present	22.0	25.0	25.0	29.7	34.6	25.1	25.4	26.7	6.49	6.4	5.7	8.6	11.1	16.5	17.8	19.3	12.7	1.67
	Mean	21.7	27.2	25.9	28.3	30.9	27.6	24.2		1.55	5.1	5.2	8.0	13.0	15.5	17.9	18.8	2.5	0.79
4	Removed	24.8	27.6	25.6	27.5	30.4	29.5	23.0	26.9		3.0	4.8	4.8	9.1	9.2	11.6	14.7	8.3	
	Present	14.8	30.6	24.4	22.8	35.1	28.0	20.9	25.2	7.91	3.6	4.1	6.7	9.2	13.3	12.4	14.2	9.5	1.26
	Mean	19.8	29.1	25.0	25.2	32.8	28.8	21.9		1.72	3.3	4.5	5.8	9.1	11.2	12.1	14.5		0.69
7	Removed	17.8	16.1	11.0	19.0	21.2	23.0	22.6	18.7		2.7	3.6	4.2	5.1	4.2	5.2	7.9	4.8	
	Present	15.3	23.1	15.3	18.5	23.0	21.2	15.5	18.8	7.33	2.9	3.2	5.2	5.9	5.5	6.3	9.4	5.7	0.17
	Mean	16.6	19.6	13.1	18.8	22.1	22.1	19.0		1.65	2.8	3.4	4.7	5.5	4.9	5.8	8.7		0.25

[1] Within days the upper value is standard error for water treatments and lower value is standard error for sward disturbance.

[2] Pre-water treatment.

Table 34. Soil water at the 3-30 cm depth of the profile on 4 days following addition of 0-25 mm of water on plots in which clubmoss was present or removed in may and June 1998.

		May									Jun.								
		Water added (mm)																	
Day	Clubmoss treatment	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]
		(%)																	
0[1]	Removed	6.8	7.7	7.8	8.0	7.4	6.7	7.6	7.4		3.0	2.9	3.1	2.9	2.9	3.2	2.9	3.0	
	Present	6.9	7.8	7.6	7.6	7.0	7.8	6.9	7.4	0.14	3.2	2.7	3.0	3.4	3.0	3.2	2.7	3.0	0.04
	Mean	6.9	7.7	7.7	7.8	7.2	7.3	7.3		0.23	3.1	2.8	3.0	3.1	2.9	3.2	2.8		0.12
1	Removed	9.5	7.7	8.0	8.7	8.4	9.7	9.8	8.8		3.5	2.9	4.2	5.0	7.0	6.9	7.0	5.2	
	Present	7.1	6.9	9.8	8.3	8.4	9.8	9.4	8.5	0.70	2.9	2.7	3.7	4.1	5.4	7.6	5.5	4.6	0.29
	Mean	8.3	7.3	8.9	8.5	8.4	9.7	9.6	8.7	0.51	3.2	2.8	3.9	4.6	6.2	7.2	6.2		0.33
2	Removed	6.7	7.1	7.2	7.0	8.0	9.4	9.8	7.9		3.8	3.6	4.0	5.3	6.4	6.5	6.8	5.2	
	Present	7.2	5.8	8.2	8.2	7.8	9.0	9.3	7.9	0.35	2.6	2.8	3.2	6.0	6.4	5.9	5.5	4.6	0.20
	Mean	6.9	6.5	7.7	7.6	8.0	9.2	9.5		0.36	3.2	3.2	3.6	5.7	6.4	6.2	6.2		0.27
4	Removed	6.2	7.0	7.1	7.6	7.9	8.3	8.3	7.5		2.8	2.4	2.9	3.6	3.8	4.7	5.1	3.6	
	Present	6.8	7.3	8.5	7.9	7.7	9.1	8.4	7.9	0.11	2.5	2.6	3.5	3.8	4.2	5.3	4.6	3.8	0.07
	Mean	6.5	7.1	7.8	7.7	7.9	8.7	8.3		0.20	2.7	2.5	3.2	3.7	4.0	5.0	4.9	3.7	0.17
7	Removed	6.1	6.4	6.0	6.2	6.8	7.1	8.2	6.7		2.4	2.5	2.7	2.9	3.3	3.8	4.2	3.1	
	Present	5.9	6.5	7.2	7.4	6.8	7.8	8.2	7.1	0.16	2.3	2.4	3.2	3.8	4.5	4.5	4.7	3.6	0.11
	Mean	6.0	6.5	6.6	6.8	6.8	7.5	8.2		0.25	2.4	2.5	3.0	3.4	3.9	4.2	4.4		0.20

[1] Within days the upper value is standard error for water treatments and lower value is standard error for sward disturbance.

[2] Pre-water treatment.

Table 35. Soil water at the 3-30 cm depth of the profile on 4 days following addition of 0-25 mm of water on plots in which clubmoss was present or removed in July and August 1998.

Table 35. Soil water at the 3-30 cm depth of the profile on 4 days following addition of 0-25 mm of water on plots in which clubmoss was present or removed in July and August 1998.

		Jul.									Aug.								
		Water added (mm)																	
Day	Clubmoss treatment	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]
		(%)																	
0[2]	Removed	10.2	9.7	11.4	10.5	9.4	11.1	12.3	10.7		2.1	2.1	2.0	1.8	1.9	1.7	1.8	1.9	
	Present	10.5	11.3	10.7	11.2	11.7	11.1	11.5	11.2	0.44	2.1	2.1	1.9	1.9	1.9	1.8	2.0	1.9	0.01
	Mean	10.3	10.5	11.1	10.9	10.6	11.1	11.9		0.40	2.1	2.1	2.0	1.9	1.9	1.7	1.9		0.06
1	Removed	9.9	10.1	12.0	11.5	11.7	12.3	12.8	11.5		2.3	2.2	2.8	5.3	6.8	6.4	7.2	4.6	
	Present	9.8	11.2	11.0	13.0	13.6	11.8	12.3	11.8	0.43	2.3	2.4	3.2	3.5	7.2	6.8	7.2	4.9	0.29
	Mean	9.9	10.7	11.5	12.2	12.6	12.1	12.6		0.40	2.3	2.3	3.0	4.5	6.7	6.7	7.2		0.33
2	Removed	7.8	9.1	9.9	9.7	9.2	10.0	10.6	9.5		2.3	2.2	3.2	4.8	4.6	7.0	6.3	4.3	
	Present	8.2	10.6	9.5	11.1	10.4	9.5	10.0	9.9	0.30	2.7	2.7	3.0	4.2	6.1	6.2	6.3	4.6	5.15
	Mean	8.0	9.9	9.7	10.4	9.8	9.8	10.4		0.33	2.4	3.1	4.5	5.4	6.6	6.3	4.5		1.39
4	Removed	9.0	8.2	7.7	8.6	8.7	9.7	9.6	8.8		2.2	2.3	2.5	4.3	3.9	5.9	5.2	3.8	
	Present	6.7	9.3	8.5	9.5	9.6	9.1	8.7	8.8	0.57	2.4	2.4	2.9	3.0	5.3	4.8	5.6	3.9	0.36
	Mean	7.9	8.8	8.1	9.1	9.2	9.4	9.1		0.46	2.3	2.4	2.7	3.8	4.6	5.3	5.4		0.37
7	Removed	6.5	6.5	6.2	6.3	7.0	7.4	7.7	6.8		2.2	2.2	2.7	3.5	3.7	2.9	4.7	3.1	
	Present	6.1	7.5	6.9	6.9	7.4	7.2	7.1	7.0	0.13	2.2	2.5	2.9	2.9	3.8	3.8	5.0	3.4	0.07
	Mean	6.3	7.0	6.5	6.6	7.2	7.3	7.4		0.22	2.2	2.3	2.8	3.2	3.8	3.4	4.8		0.16

[1] Within days the upper value is standard error for water treatments and lower value is standard error for sward disturbance.

[2] Pre-water treatment.

Table 36. Mid-day leaf xylem water potentials on 4 days for Junegrass in May and June 1998 following addition of 0-25 mm of water on plots with clubmoss present or removed.

		May									Jun.								
		Water added (mm)																	
Day	Clubmoss treatment	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]
		Leaf xylem water potential (-MPa)																	
0[2]	Absent	1.8	1.6	1.5	1.9	1.7	1.2	1.6	1.6		3.2	3.8	3.9	4.1	3.7	2.6	4.0	3.6	
	Present	1.8	1.6	2.3	2.1	1.9	1.5	1.6	1.8	0.04	3.3	3.4	3.6	3.1	3.9	3.2	3.0	3.4	0.17
	Mean	1.8	1.6	1.9	2.0	1.8	1.4	1.6		0.12	3.3	3.6	3.7	3.6	3.8	2.9	3.5		0.25
1	Absent	2.1	1.9	1.7	1.7	1.4	1.8	1.8	1.7		2.7	1.5	1.3	0.8	0.8	0.8	1.2	1.3	
	Present	1.7	2.0	2.3	1.7	1.4	2.2	1.4	1.8	0..07	2.8	1.3	1.6	1.0	0.7	0.7	0.9	1.3	0.02
	Mean	1.9	1.9	2.0	1.7	1.4	2.0	1.6		0.16	2.8	1.4	1.4	0.9	0.7	0.8	1.0		0.09
2	Absent	1.2	1.2	1.1	1.4	0.9	1.0	0.8	1.1		2.6	2.9	2.7	1.4	1.2	1.0	1.9	1.9	
	Present	1.1	0.8	1.0	1.0	1.5	1.0	1.2	1.1	0.06	3.0	1.9	1.5	1.8	1.2	1.9	1.6	1.8	0.25
	Mean	1.2	1.0	1.1	1.2	1.2	1.0	1.0		0.14	2.8	2.4	2.1	1.6	1.2	1.5	1.7		0.30
4	Absent	2.5	2.3	2.4	2.4	2.6	2.2	2.6	2.4		2.0	3.7	2.2	2.5	1.7	1.7	1.9	2.3	
	Present	2.5	2.0	2.5	2.4	2.1	2.2	2.6	2.3	0.03	2.9	2.4	2.6	1.5	1.4	1.7	1.3	2.0	0.28
	Mean	2.5	2.1	1.5	2.4	2.3	2.2	2.6		0.10	2.5	3.0	2.4	2.0	1.5	1.7	1.6		0.32
7	Absent	2.2	1.9	2.1	2.0	1.8	2.0	2.9	2.1		2.5	2.8	2.5	2.4	2.3	2.1	2.5	2.4	
	Present	2.5	2.4	1.6	1.7	1.7	1.9	2.4	2.0	0.07	2.9	2.2	2.2	1.9	1.8	1.8	1.4	2.0	0.09
	Mean	2.3	2.1	1.8	1.8	1.7	1.9	2.6		0.16	2.7	2.5	2.3	2.1	2.0	1.9	1.9		0.19

[1] Within days the upper value is standard error for water treatments and lower value is standard error for sward disturbance.

[2] Pre-water treatment.

Table 37. Mid-day leaf xylem water potentials on 4 days for blue grama in July and August 1998 following addition of 0-25 mm of water on plots with clubmoss present or removed.

		Jul.									Aug.								
		Water added (mm)																	
Day	Clubmoss treatment	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]	0.0	2.5	5.0	10.0	15.0	20.0	25.0	Mean	SE[1]
		Leaf xylem water potential (-MPa)																	
0[2]	Absent	1.0	1.0	1.3	1.1	1.0	1.4	1.0	1.1		4.0	3.9	4.1	3.8	5.8	5.8	3.1	4.3	
	Present	1.3	1.2	0.8	1.1	1.1	1.1	1.3	1.1	0.03	5.6	2.9	3.2	4.6	4.3	4.8	4.2	4.2	0.44
	Mean	1.2	1.1	1.1	1.1	1.1	1.3	1.2		0.10	4.8	3.4	3.7	4.1	5.0	5.2	3.6		0.40
1	Absent	1.2	1.5	1.3	0.8	1.5	0.9	0.7	1.1		4.1	2.5	2.0	1.4	0.9	0.9	0.5	1.7	
	Present	1.1	0.7	1.2	1.3	1.0	1.3	1.2	1.1	0.09	3.0	3.6	1.2	1.4	0.6	0.7	0.7	1.4	0.17
	Mean	1.2	1.1	1.2	1.0	1.2	1.1	1.0		0.18	3.5	3.0	1.6	1.4	0.7	0.8	0.6		0.25
2	Absent	0.7	0.6	0.6	0.7	0.5	0.6	0.5	0.6		3.6	2.8	1.9	0.9	1.0	1.0	0.7	1.7	
	Present	0.7	0.4	0.5	0.6	0.6	0.5	0.7	0.6	0.00	4.0	2.5	2.3	2.0	1.1	0.9	0.8	1.8	0.08
	Mean	0.7	0.5	0.6	0.6	0.5	0.5	0.6		0.04	3.8	2.7	2.1	1.4	1.0	0.9	0.7		0.17
4	Absent	1.5	1.4	1.5	1.3	1.5	1.4	1.4	1.4		4.3	3.9	3.7	2.6	1.8	1.7	1.9	2.8	
	Present	1.6	1.4	1.5	1.5	1.4	1.4	1.5	1.5	0.00	4.1	1.8	2.5	1.7	1.7	1.1	1.6	2.0	0.20
	Mean	1.5	1.4	1.5	1.4	1.5	1.4	1.5		0.04	4.2	3.0	3.1	2.2	1.7	1.3	1.7		0.27
7	Absent	1.7	1.5	1.6	1.5	1.5	1.6	1.1	1.5		4.0	2.8	4.0	1.6	2.8	2.0	1.4	2.6	
	Present	1.5	1.3	1.4	1.5	1.1	1.3	1.5	1.4	0.02	3.0	3.5	3.0	1.2	1.9	1.3	1.3	2.1	0.17
	Mean	1.6	1.4	1.5	1.5	1.3	1.4	1.3		0.09	3.5	3.1	3.5	1.4	2.3	1.6	1.3		0.25

[1] Within days the upper value is standard error for water treatments and lower value is standard error for sward disturbance.

[2] Pre-water treatment.

Table 38. Probabilities that contrasts of mean soil water in the 0-3 and 3-30 cm depth of the profile and mid-day leaf xylem water potentials are different on 4 days in plots with clubmoss present or removed following addition of 0-25 mm of water in 4 months in 1998. Bold values indicate contrasts are significantly different ($P \leq 0.05$).

Water treatment (mm)		May					Jun.					Jul.					Aug.				
		Day																			
		0[1]	1	2	4	7	0[1]	1	2	4	7	0[1]	1	2	4	7	0[1]	1	2	4	7
		Calculated probability																			
0.0	Soil water	0.826	0.345	0.382	0.838	0.477	0.081	0.343	0.219	0.732	0.269	0.678	0.851	0.904	**0.042**	0.634	0.320	0.312	0.428	0.862	0.892
2.5	(0-3 cm)	**0.012**	0.731	0.938	**0.044**	0.118	0.568	0.430	0.790	0.507	0.985	0.670	0.160	0.291	0.533	0.186	**0.009**	0.189	0.842	0.481	0.284
5.0		0.609	0.227	0.274	0.578	0.325	**0.032**	**0.015**	0.557	0.588	0.939	0.579	0.504	0.658	0.792	0.410	0.849	0.109	0.660	0.438	0.359
10.0		0.488	0.698	0.086	0.712	0.065	0.937	0.253	0.621	0.923	0.789	0.919	0.346	0.495	0.337	0.914	0.146	**0.026**	**0.013**	0.370	0.544
15.0		0.674	0.737	0.594	0.919	0.721	0.327	0.151	0.906	0.916	0.716	0.110	0.419	0.079	0.331	0.731	0.447	0.529	0.434	0.106	0.220
20.0		0.443	0.470	0.382	0.863	0.774	0.139	0.501	0.448	0.988	0.541	0.509	0.796	0.237	0.750	0.731	0.775	0.101	0.080	0.136	**0.033**
25.0		0.068	0.670	0.673	0.077	**0.049**	0.387	0.421	0.481	0.136	0.131	0.606	0.958	0.536	0.662	0.180	1.000	0.568	0.668	0.822	0.189
0.0	Soil water	0.875	0.078	0.432	0.324	0.708	0.739	0.548	0.213	0.676	0.875	0.782	0.941	0.675	**0.035**	0.511	0.894	0.977	0.697	0.784	0.958
2.5	(3-30 cm)	0.975	0.542	0.068	0.620	0.881	0.465	0.841	0.373	0.835	0.875	0.189	0.230	0.054	0.289	0.111	**0.006**	0.713	0.777	0.277	0.493
5.0		0.754	0.163	0.147	**0.033**	0.072	0.739	0.581	0.373	0.513	0.387	0.544	0.274	0.586	0.453	0.291	0.594	0.572	0.860	0.383	0.562
10.0		0.572	0.760	0.113	0.591	0.077	0.131	0.395	0.503	0.811	0.172	0.526	0.112	0.084	0.365	0.364	0.068	**0.004**	**0.021**	**0.000**	**0.012**
15.0		0.638	0.970	0.775	0.772	1.000	0.947	0.125	0.933	0.655	0.054	0.062	**0.045**	0.147	0.399	0.511	0.894	0.198	**0.040**	**0.003**	0.833
20.0		0.182	0.909	0.551	0.204	0.296	0.947	0.453	0.521	0.513	0.273	1.000	0.582	0.477	0.573	0.723	**0.021**	**0.029**	0.196	0.444	**0.002**
25.0		0.434	0.717	0.497	0.804	0.910	0.506	0.125	0.159	0.592	0.455	0.544	0.533	0.558	0.399	0.391	0.289	0.977	0.972	0.354	0.430
0.0	Mid-day leaf	1.000	0.315	0.671	0.865	0.496	0.871	0.846	0.431	0.148	0.442	0.110	0.694	0.846	0.718	0.470	**0.038**	0.341	0.696	0.831	0.388
2.5	xylem water	0.932	0.736	0.238	0.499	0.197	0.545	0.771	**0.040**	**0.030**	0.321	0.282	**0.003**	0.335	0.904	0.547	0.003	0.866	0.206	**0.009**	0.834
5.0	potentials	**0.008**	**0.075**	0.865	0.735	0.197	0.704	0.595	**0.022**	0.515	0.556	**0.023**	0.694	0.562	0.904	0.470	0.109	0.416	0.595	0.197	0.214
10.0		0.611	1.000	0.154	0.955	0.457	0.095	0.699	0.431	0.093	0.343	0.718	0.054	0.846	0.401	0.904	0.515	0.714	0.416	0.156	0.421
15.0		0.611	0.840	0.067	0.240	0.901	0.716	0.961	0.958	0.597	0.299	0.857	0.072	0.699	0.904	0.152	**0.007**	0.736	0.887	0.894	0.248
20.0		0.354	0.315	0.799	0.955	0.804	0.296	0.846	**0.071**	0.903	0.526	0.211	0.154	0.699	0.904	0.337	0.457	0.978	0.915	0.852	0.765
25.0		0.932	0.229	0.238	1.000	0.177	0.120	0.530	0.563	0.331	0.051	0.077	**0.030**	0.335	0.904	0.152	**0.042**	0.822	0.915	0.689	0.976

[1] Pre-water treatment.

Discussion

Processes that govern water relations in rangeland must be maintained through careful management of resources to maximize the functions of range ecosystems. The primary process governing water relations on rangeland is the hydrologic cycle which in turn is affected by climate, physical characteristics of the ecosystem, and past and present land management. Through this cycle, water is received as precipitation, captured, stored, and eventually released back into the atmosphere. Vegetation has large impacts on the hydrologic cycle. Even though climatic conditions cannot be controlled, factors such as the amount of live and dead plant material can be managed to influence components of the hydrologic cycle and increase the effectiveness of precipitation. For example, the interactions of vegetation, the intensity and amount of precipitation, and site characteristics have large effects on infiltration of water. In some situations, vegetation increases infiltration by slowing runoff (Heady *et al.* 1994), while dead vegetation on the soil surface can have positive (Weaver *et al.* 1952, Hopkins 1954, Willms *et al.* 1993) or negative effects (Couturier *et al.* 1973, Dickinson 1983) depending on the vegetation type and amount, the environment, and physical characteristics of the site. Vegetation also plays key roles in the storage of water in rangeland ecosystems (Rauzi 1960). Plants contribute organic matter to soil, increasing the water holding capacity of the profile and live and dead plant material helps to prevent soil erosion.

Previous studies in Mixed Prairie revealed that litter has highly variable effects on soil water. These effects varied depending upon the amount, shape and surface characteristics of the vegetation, the type, intensity, and amount of precipitation (Couturier *et al.* 1973), and the time of year (Hopkins 1954). In other studies, litter was generally considered beneficial to the hydrologic cycle because it increased infiltration (Weaver *et al.* 1952), decreased soil temperature, and insulated the soil against incident solar radiation (Willms *et al.* 1986). By comparison, litter can have negative effects on soil water, the severity of which is related to the total amount of precipitation (Naeth *et al.* 1991). Naeth *et al.* (1991) concluded that interception of precipitation by litter was relatively small from large storms, but it was high from small events.

Release of water from the soil is also largely controlled by vegetation. Through growth and respiration, plants remove water from the soil and release it into the atmosphere through leaves. On the other hand, vegetation may reduce the loss of soil water by reducing evaporation by providing cover that shades the soil surface from solar radiation.

Many of the beliefs about the influence of clubmoss on soil and plant water relations in Mixed Prairie were derived from assumptions about how it affected various aspects of the hydrologic cycle. For example, Dolan *et al.* (1972) hypothesized that clubmoss increases biomass production by reducing runoff and increasing infiltration in some areas, but it may reduce production on other sites by competing with plants for soil water. The relationship between clubmoss and soil water lead Dolan *et al.* (1972) and others (Dolan 1966, Wagner 1966, Taylor 1967) to conclude that extensive clubmoss cover ultimately reduces productivity. Similarly, Majarowicz (1963) proposed that clubmoss decreased soil water by absorbing precipitation and reducing infiltration. The purpose of the present studies was to determine the impact of clubmoss on soil water, plant water status, and productivity in Mixed Prairie by manipulating clubmoss and precipitation.

In the present studies, clubmoss did not have a consistent effect on soil water and leaf xylem water potentials. Removing clubmoss from the sward or killing it did not consistently increase or reduce soil water or leaf xylem water potentials, regardless of whether precipitation was reduced, supplemented with irrigation, or not manipulated. In addition, clubmoss was not detrimental or beneficial to leaf xylem water potentials and soil water over a range of simulated precipitation events that were 0.0 mm to 25 mm. Even though killing or removing clubmoss did not affect water relations, supplementing precipitation by irrigating or reducing water with rain-out shelters consistently increased or decreased soil water and leaf xylem water potentials. These findings indicate that environmental conditions, particularly the amount of precipitation, have far greater affects on soil water and leaf xylem water potentials than clubmoss. The hypothesis that clubmoss affects soil water and plant water status is therefore rejected.

Albertson *et al.* (1957) concluded that one of the first responses of rangeland to drought is decreased productivity. Clarke *et al.* (1947) also proposed that annual fluctuations in biomass production were closely linked to climate. They (Clarke *et al.* 1974) concluded that precipitation, evaporation, mean seasonal temperature, hours of bright sun, and wind speed were all correlated to varying degrees with biomass production. Smoliak (1986), on the other hand, concluded that the amount of precipitation received from April through July was highly correlated with biomass production, and Johnston (1969) found that precipitation of the previous fall and biomass production were correlated. Other researchers studying the effect of climate on biomass production found close relationships between soil water and plant biomass (Rogler *et al.* 1946).

Although earlier studies indicated a strong influence of climate on biomass production, abundant precipitation will not guarantee greater production. Perry (1976) concluded that the complexity of rangeland ecosystems makes predicting the response of vegetation to precipitation difficult. In fact, the response of rangeland vegetation to increased precipitation is dependent on nutrient cycling, timing and amount of precipitation, range condition, vigor of plants, range site characteristics, stage of growth, genetic limitations of the vegetation, and past management. Difficulty predicting response of rangeland vegetation to altered resource availability is further complicated by the differential response of each species in the sward (Olson 1985).

Response of biomass production to manipulation of precipitation in the current studies support the conclusions of Perry (1976) and Olson (1985). Supplementing precipitation by irrigating consistently increased total graminoid production relative to reducing precipitation, but there was no difference when production under ambient precipitation was compared to irrigating or the treatment of reduced precipitation. In addition, the response of different species is highly variable, further decreasing the predictability of response to precipitation. In the present study for example, response of total standing crop to precipitation treatments varied from year-to-year, biomass production of Junegrass and blue grama was often different, and forb production was generally not affected by sward disturbances or precipitation treatments. Therefore, when soil and plant water status are considered with production data, it appears that clubmoss does not increase or decrease total biomass production, or that of graminoids and forbs. The hypothesis that clubmoss affects biomass production by altering soil and plant water relations is therefore rejected.

Although removing clubmoss from the sward did not affect soil and leaf xylem water potentials or biomass production, the physical effects of mechanically disturbing rangeland likely did affect these variables by influencing the hydrologic cycle. The amount of bare ground in the sward following mechanical disturbance and clubmoss removal was similar, while little bare ground was present in control, plots where nitrogen was added, or in those where clubmoss was killed with glyphosate. Although the cover components were different, soil water and leaf xylem water potentials were similar among all disturbances, probably because evaporative losses from bare ground in plots with clubmoss removed and mechanical disturbance were balanced with losses to evapotranspiration in the other sward disturbances. The lack of difference in soil water and leaf xylem water potentials regardless of clubmoss being present or absent indicates that its affects on these aspects of the hydrologic cycle are minimal. Also, because no differences in soil water or leaf xylem water potentials were observed among sward disturbances, any difference in production reflects the response of the plants to other factors such as competition and the availability of soil resources.

Mechanically disturbing the sward did not consistently increase production of graminoids or total standing crop, and adding nitrogen generally had no influence. This response was likely caused by unreliable or insufficient soil water and nitrogen following the mechanical disturbance to consistently increase productivity and compensate for the loss of individual plants from the sward. On the other hand, the lack of response to nitrogen fertilizer may reflect the high competition for resources among members of an undisturbed community. By contrast, when plants are killed by mechanical disturbance, the remaining individuals are often released from competition and grow larger as was the case Junegrass and blue grama. Mechanically disturbing the sward generally increased the weight of individual tillers, culms, and inflorescences of Junegrass and blue grama relative to control and adding nitrogen. Compared to control, however, adding nitrogen had variable effects, but often no differences were detected for weights of inflorescences, culms, or total biomass in these two treatments. Irrigating, on the other hand, did not alter biomass of Junegrass or blue grama, but reducing precipitation consistently decreased at least one biomass component for each species. Removing or killing clubmoss, however, usually had no affect on weights of individual tillers of Junegrass and blue grama relative to control.

Overall, when biomass components of individual plants of Junegrass and blue grama and community level production are considered together, mechanically disturbing the sward or reducing precipitation have greater influence on productivity than does clubmoss. The hypothesis that clubmoss limits production is therefore rejected and the alternative hypothesis that water deficits limit production is proposed.

Clubmoss and Precipitation Effects on Emergence and Survival of Seedlings of Native Grasses and Forbs

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Abstract

Many practitioners of range management have suggested that clubmoss (*Selaginella densa*) limits emergence and survival of grass and forb seedlings. This study was conducted in 1997 and 1998 on two sandy range sites in low-fair condition in south-central Saskatchewan to isolate the effects of clubmoss and precipitation on emergence and survival of seedlings of native grasses and forbs. Microsites (live clubmoss, dead clubmoss, bare soil, and litter) where seedlings emerged and survived were also determined. Precipitation treatments were applied at 3 levels including 40 mm of water added by irrigating once per month in addition to natural precipitation, precipitation reduced by using rain-out shelters, and control or natural precipitation. Seedbed treatments, applied in all combinations with precipitation treatments included: 1) control (undisturbed sward); 2) clubmoss killed with Glyphosate (clubmoss present, but dead), and; 3) clubmoss physically removed from the seedbed by raking. Seedlings were counted 2- to 4-week intervals from May through August 1997 and 1998; survival of seedlings was determined at the end of August each year. Emergence of native seedlings is strongly limited by precipitation because in all cases emergence of seedlings was greatest when irrigated. In two of three years, survival of seedlings was also limited by precipitation while in one year survival was not affected by precipitation or seedbed conditions. Emergence and survival of seedlings in different plant groups (grasses vs. forbs), seedbed characteristics, and year, preclude any general statements about beneficial, neutral, or negative effects of clubmoss on emergence and survival of native grasses and forbs. It is concluded that site conditions, timing, frequency and intensity of precipitation, and other environmental factors likely interact to illicit unique seedling emergence and survival. The hypotheses that precipitation limits emergence of seedlings is accepted. However, because no consistent effects of clubmoss on seedling emergence and survival were observed, the hypothesis that clubmoss has negative effects on seedling dynamics is rejected. Alternatively, the hypothesis that environmental conditions limit emergence and establishment more than clubmoss is proposed. Provided seeds are present in the soil seedbank, management activities that improve the water balance on a site appear more important in promoting seedling emergence and survival of perennial grasses and forbs than activities that are designed to reduce cover of clubmoss.

Introduction

Clubmoss (*Selaginella densa* Rydb.) is a low, densely matted, non-flowering plant with roots penetrating to 5 cm in the soil (Webster and Steeves 1964, Van Dyne and Vogel 1967, Moss 1983). Within Northern Mixed Prairie clubmoss is an important part of the vegetation, covering 6-25% of the soil surface (Coupland 1950). In some areas of the Great Plains clubmoss can cover up to 80% of the soil surface (Dolan and Taylor 1971). Clubmoss is most important in the *Stipa-Bouteloua* association of Northern Mixed Prairie (Coupland 1950).

Clubmoss has a remarkable ability to survive extreme drought conditions, with a laboratory specimen being revived after 33 months of drought (Webster and Steeves (1964). Van Dyne and Vogel (1967) suggested clubmoss is capable of utilizing small, late summer precipitation events that are not beneficial to associated C_3 grasses. Within the grassland ecosystem *Selaginella* spp. are thought to "fill the niche of locally transient, but regionally permanent open xeric habitats" (Van Dyne and Vogel 1967). In particular clubmoss may assist in the prevention of wind erosion and ameliorate the effects of trampling (Smoliak *et al.* 1982). It is believed that seedling establishment is not affected by clubmoss in years of abundant precipitation (Smoliak *et al.* 1982). Because clubmoss comprises a large component of the basal cover in Northern Mixed Prairie it is an important component of the seedbed ecology of this region (Bai and Romo 1995).

The objective of this study was to isolate the effects of water and clubmoss on emergence and survival of seedlings of native grasses and forbs in Northern Mixed Prairie. The hypotheses tested were: 1) clubmoss restricts emergence of seedlings, and 2) water deficits restrict emergence of seedlings. To test these hypotheses, the following aspects were investigated: 1) effects of precipitation on seedling emergence and first-year survival of native grasses and forbs; 2) effect of clubmoss on seedling emergence and first-year survival of native grasses and forbs; 3) combined effect of precipitation and clubmoss on seedling emergence and first-year survival of native grasses and forbs, and; 4) effect of microsite type on emergence and first-year survival of seedlings of native grasses and forbs.

Materials and Methods

Study Site

Studies were conducted at the Prairie Farm Rehabilitation Administration's Rudy-Rosedale community pasture about 60 km south of Saskatoon, Saskatchewan. Temperatures in this area vary from an average of -17.1°C in January to 19.1°C in July (Environment Canada 1982). Precipitation averages 315 mm with about 65% received in April through August (Environment Canada 1982). Soils of the site are Asquith Orthic Dark Brown with a sandy loam texture (Ellis *et al.* 1970). Condition of this sandy range site is estimated at low fair (J.T. Romo, personal observation), with *Koeleria cristata* (Junegrass), *Stipa comata* (needle-and-thread), and *Bouteloua gracilis* (blue grama) dominating. Grazing by cattle was excluded during the experiment.

Experimental Design and Plot Layout

Studies were established as a randomized-complete-block-design with 3 X 5 factorial treatments of precipitation and seedbed conditions in each of 4 replicates. Studies were begun in April 1997 at Dundurn, and in April 1998 at Rudy. The Dundurn and Rudy study sites are about 2 km apart. Treatments were applied to 3 X 3 m plots in which a 2 X 2 m observation area was established in the center. Measurements were restricted to the center of each plot to reduce potential edge effects. Each 3 X 3 m plot was surrounded on all sides with a 3 m buffer of undisturbed vegetation. Three seedbed treatments, all imposed only once in early May 1997 or May 1998, included: 1) control where no treatment was applied; 2) clubmoss killed with a 33% Glyphosate solution (clubmoss present but dead), and; 3) clubmoss physically removed by raking the clubmoss off the soil surface with a garden rake. Three precipitation regimes included control in which natural precipitation was allowed. The second treatment, irrigation, included addition of 40 mm of water in 1 event each by irrigating plots in mid-May, mid-June, mid-July, and mid-August, for a total of 160 mm above that of natural precipitation. In the third treatment rain-out shelters were constructed from greenhouse polyethylene to reduce precipitation reaching plots, and exacerbate seasonal, drought conditions. Rain-out shelters, 3.1 X 3.1 m and covering the entire 3 X 3 m plot, were erected in early May. Rain gauges were placed in 3 control plots and under 3 rain-out shelters; precipitation was recorded at 1 to 3 day-intervals.

Seedling Dynamics and Soil Water

After extensive consideration, potential microsites for seedling emergence were defined and categorized as: 1) live clubmoss; 2) dead clubmoss; 3) bare soil, and; 4) litter covered soil. Established bunchgrasses were considered a microsite, but few seedlings emerged from them; therefore, bunchgrasses were not included in analyses. Percent coverage of the soil surface by each microsite was determined in each site and plot in May 1997 and May 1998 using a point-frame. In each replicate plot, microsites were categorized among 100 points

Seedlings were monitored in a permanent, 0.5 X 0.5 m quadrat in each replicate, in all possible combinations of precipitation and seedbed treatments. Seedling emergence was determined at about 2-week intervals from May through August at Dundurn in 1997, and May through August at Rudy in 1998. In 1998 observations at the Dundurn site were conducted once in mid-May, mid-June, mid-July, and mid-August. On each date individual seedlings were marked with color-coded toothpicks, and the microsite where each seedling emerged was recorded. Survival of cohorts, seedlings emerged on a date, was determined at the end of August.

Soil water in the 0-5 cm depth was determined at 2-week intervals. Soil samples were collected using a 2.5-cm diameter soil probe, samples were placed in metal soil cans, cans were sealed, transported to the laboratory, and weighed. Samples were dried 48 hours at 80°C, re-weighed, and soil water content was calculated as **(Eq. 1)**:

$$\text{Soil water (\%)} = [(\text{Wet weight} - \text{Dry weight})/\text{Dry weight}] \times 100 \qquad \textbf{Eq. 1}$$

A pressure plate was used to determine water content at field capacity (-0.03 MPa) and permanent wilting point (-1.5 MPa) for the 0-30 cm depth of the soil profile. Respectively, soil water content at -0.03 and -1.5 MPa averaged 8.5 % (SE±0.47) and 6.9 % (SE±0.43) at Dundurn, and 8.1 % (SE±0.42) and 7.4% (SE±0.41) at Rudy.

Data Analysis

Before analysis, data were transformed using $\sqrt{(y + 0.5)}$. Seedbed effects on the number of seedlings emerging and the number surviving within each cohort were tested with factorial analyses of variance (Snedecor and Cochran 1980). Emergence and survival were combined across cohorts in each treatment; total emergence and total survival at the end of August were tested with analyses of variance. Where treatment effects were significant ($P \leq 0.05$), means were compared using Least Significant Differences (LSD) (Snedecor and Cochran 1980).

The number of seedlings emerging from different microsites was analyzed using utilization-availability analysis (Neu *et al.* 1974) by combining the number of emerging seedlings within each cohort across all treatment combinations. Total emergence and survival in the microsites was also tested by combining the number of seedlings across cohorts and treatments. The utilization-availability technique involves examination of a multinomial distribution, which does not follow an "expected" occurrence pattern. Following rejection of a Chi-square test for the determination of an "expected" occurrence pattern, a Bonferroni *z*-statistic is used to calculate a confidence interval based on an observed frequency of occurrence. The Bonferroni confidence interval is then compared against the expected frequency to determine if the data occur more or less frequently then expected. Statistical significance in all tests was assumed at $P \leq 0.05$.

Results

Ground Cover

In control plots, live and dead clubmoss cover averaged 32 and 37%, respectively at Dundurn, and 32 and 52%, respectively at Rudy (Table 1). Where clubmoss was removed, cover of clubmoss was reduced to 3 to 6% at Dundurn, and 3 to 8% at Rudy. Cover of bare soil at Dundurn varied from a low of 4% in control to 6% where clubmoss was killed and a high of about 55% where clubmoss was removed. At Rudy cover of bare soil was least in control (<1-1.5%), intermediate in plots where clubmoss was killed (about 3-6%), and greatest (about 30-38%) where clubmoss was removed. The proportion of the seedbed covered by bare soil and litter was 32% and 23%, respectively at Dundurn, and 18% and 25%, respectively at Rudy.

Precipitation Received During Study

Rain-out shelters and irrigation allowed creation of a strong precipitation gradient among precipitation treatments. Precipitation gradients ranged from recorded amounts of 2 to 346 mm in 1997, and 0 to 339 mm in 1998 (Table 2). Although total precipitation received in May through August varied by only 7 mm between years, the timing and amount of precipitation differed considerably.

Table 1. Basal cover of live clubmoss, dead clubmoss, and bare soil within all precipitation and seedbed treatment combinations at the Dundurn and Rudy study sites.

		---Basal cover---					
Precipitation treatment	Seedbed treatment	Live clubmoss		Dead clubmoss		Bare soil	
		---Basal cover (%)---					
		Dundurn	Rudy	Dundurn	Rudy	Dundurn	Rudy
Irrigation	Control	35.0	32.3	37.0	52.0	3.8	0.8
	Clubmoss killed	33.8	14.0	37.3	55.3	6.0	5.8
	Clubmoss removed	5.0	3.3	3.0	7.5	54.5	37.5
Reduced	Control	31.8	39.8	31.2	35.3	3.8	1.5
	Clubmoss killed	26.8	29.8	39.5	41.8	8.3	3.0
	Clubmoss removed	3.8	3.8	4.0	4.8	54.3	31.8
Control	Control	36.3	36.0	34.5	41.5	3.8	1.5
	Clubmoss killed	25.5	18.5	43.3	56.5	4.3	2.8
	Clubmoss removed	5.3	3.3	5.5	8.0	55.8	30.3

Table 2. Precipitation (mm) recorded during the study from May through August 1997 and May through August 1998.

		Precipitation treatment					
Month	Time of month (days)	Ambient conditions		Precipitation reduced		Irrigated	
		Precipitation (mm)					
		--1997--	--1998--	--1997--	--1998--	--1997--	--1998--
May	1-5	----[1]	----	----	----	----	----
	6-10	----	----	----	----	(40)[2]	(40)
	11-15	0.0	0.0	----	0.0	0.0	0.0
	16-20	5.0	11.0	----	0.0	5.0	11.0
	21-25	5.1	0.0	2.0	0.0	5.1	0.0
	26-31	0.0	2.0	0.0	0.0	0.0	2.0
June	1-5	0.0	9.0	0.0	0.0	0.0	9.0
	6-10	33.0	0.0	0.0	0.0	33.0(40)	0.0(40.0)
	11-15	0.0	0.0	0.0	0.0	0.0	0.0
	16-20	15.0	0.0	0.0	0.0	15.0	0.0
	21-25	32.0	0.0	0.0	0.0	32.0	0.0
	26-30	11.5	58.0	0.0	0.0	11.5	58.0
July	1-5	1.0	59.0	0.0	0.0	1.0	59.0
	6-10	4.0	10.0	0.0	0.0	4.0(40)	10.0(40)
	11-15	0.0	0.0	0.0	0.0	0.0	0.0
	16-20	0.0	0.0	0.0	0.0	0.0	0.0
	21-25	2.0	0.0	0.0	0.0	2.0	0.0
	26-31	0.0	0.0	0.0	0.0	0.0	0.0
August	1-5	0.0	0.0	0.0	0.0	0.0	0.0
	6-10	7.0	0.0	0.0	0.0	7.0(40)	0.0(40)
	11-15	68.5	12.0	0.0	0.0	68.5	12.0
	16-20	0.0	0.0	0.0	0.0	0.0	0.0
	21-25	2.0	18.0	0.0	0.0	2.0	18.0
	26-31	0.0	0.0	0.0	0.0	0.0	0.0
Total		186.1	179.0	2.0	0.0	346.1	339.0

[1] --- indicates precipitation data were not recorded.

[2] (40) indicates 40 mm of additional water was supplied by irrigating during this time frame.

Peaks in precipitation during June and August, and dry periods in May and July characterized 1997. In June 1997, two precipitation events were greater than 30 mm and one precipitation event of 68.5 mm was recorded in August. In 1998 precipitation greatest in June and July with daily precipitation events of 58 to 59 mm in each month, respectively. In 1998 July and August were the driest months.

Seedling emergence and survival

Dundurn 1997

Soil water content declined after peaking in late May to early June, and increased in late August following a large precipitation event (Fig. 1, Table 2). Generally emergence of grass seedlings declined from late May-early June through 15 September (Fig. 1). Density of forbs emerging increased from 21 May through 11 June; this increase was followed by a decrease in emergence to late July (Fig. 2). Emergence of forb seedlings in all microsites increased sharply in late August and early September following a major precipitation event mid-August (Fig. 2).

The total number of grass and forb seedlings emerging was greatest under irrigation, intermediate under natural precipitation, least when precipitation was reduced, but similar ($P>0.05$) in different seedbeds (Table 3). Survival of all cohorts combined was influenced by precipitation and seedbed treatments (Table 3). The density of surviving seedlings was more than 3-fold greater in control than where clubmoss was removed or killed. Irrigating or reducing precipitation favored and reduced seedling survival, respectively, compared to control. Emergence and survival of each cohort are included in Appendix C.

Across all cohorts combined, more grass seedlings emerged and survived from live and dead clubmoss than expected (Tables 4 and 5). Emergence and survival of seedlings from bare soil was less than expected. The number of seedlings emerging from litter was proportional to cover of litter, but density of surviving seedlings was less than expected. The number of grass seedlings emerging in each cohort in relation to microsites is included in Appendix C.

Combined across all cohorts, emergence of forbs was less than expected from live and dead clubmoss, and greater than predicted from bare soil and litter (Table 4). Seedlings survived in live clubmoss, dead clubmoss, and litter in proportion to the cover of these seedbed types, while survival was less than expected from bare soil despite greater emergence than expected (Table 5). The number of forb seedlings emerging in each cohort in relation to microsites is included in Appendix C.

Dundurn 1998

Soil water content was least in mid-June and peaked in mid-July (Fig. 3). High numbers of grass seedlings emerged in all microsite types except litter at the same time soil water peaked (Fig. 3). Highest densities of forbs emerged in mid-July with most seedlings emerging in bare soil and live clubmoss (Fig. 4).

Total emergence of seedlings across all cohorts was greater when irrigated than under conditions of reduced and natural precipitation (Table 6). Fewer seedlings emerged from control than where clubmoss was killed or removed (Table 6). Averaged across all cohorts, seedling survival was about 2-fold greater under irrigation than under conditions of reduced and natural precipitation (Table 6). Emergence and survival of each cohort are included in Appendix C.

Combined across all cohorts, emergence of grass seedling from bare soil was greater than expected (Table 7). Fewer than the expected grass seedlings emerged from all other microsites. The density of grass seedlings surviving was greater than expected in dead clubmoss and proportional to the cover of live clubmoss and bare soil (Table 8). Less than the expected number of grass seedlings survived if they emerged from litter. Across all cohorts, the density of emerging and surviving forbs was greater than expected in bare soil, less than expected from dead clubmoss and litter, and proportional to the cover of live clubmoss (Tables 7 and 8). The number of grass and forb seedlings emerging in each cohort in relation to microsites is included in Appendix C.

Rudy 1998

Emergence of grass and forb seedlings peaked in conjunction with soil moisture in early July (Figs. 5 and 6). Seedling emergence was affected by the interacting effects of precipitation and seedbed (Table 9). The density of emerging seedlings was greatest clubmoss when was removed and when irrigated. Fewest seedlings emerged when precipitation was natural or reduced and clubmoss was killed or the seedbed was not disturbed. Few grass and forb seedlings survived over the summer; survival was not affected by seedbed conditions and precipitation ($P > 0.05$) (Table 9).

Combined across all cohorts, more than the expected number of grass seedlings emerged in dead clubmoss and bare soil, but fewer than expected grass seedlings emerged from live clubmoss and litter (Table 10). The density of forb seedlings that emerged was greatest in bare soil. Emergence and survival of each cohort are included in Appendix C.

No grass seedlings survived at Rudy in 1998 (Table 11). The density of forb seedlings surviving was greater than expected in bare soil, but less than expected in clubmoss. Survival of forbs was proportional to the cover of litter. The number of grass and forb seedlings emerging in each cohort in relation to microsites is included in Appendix C.

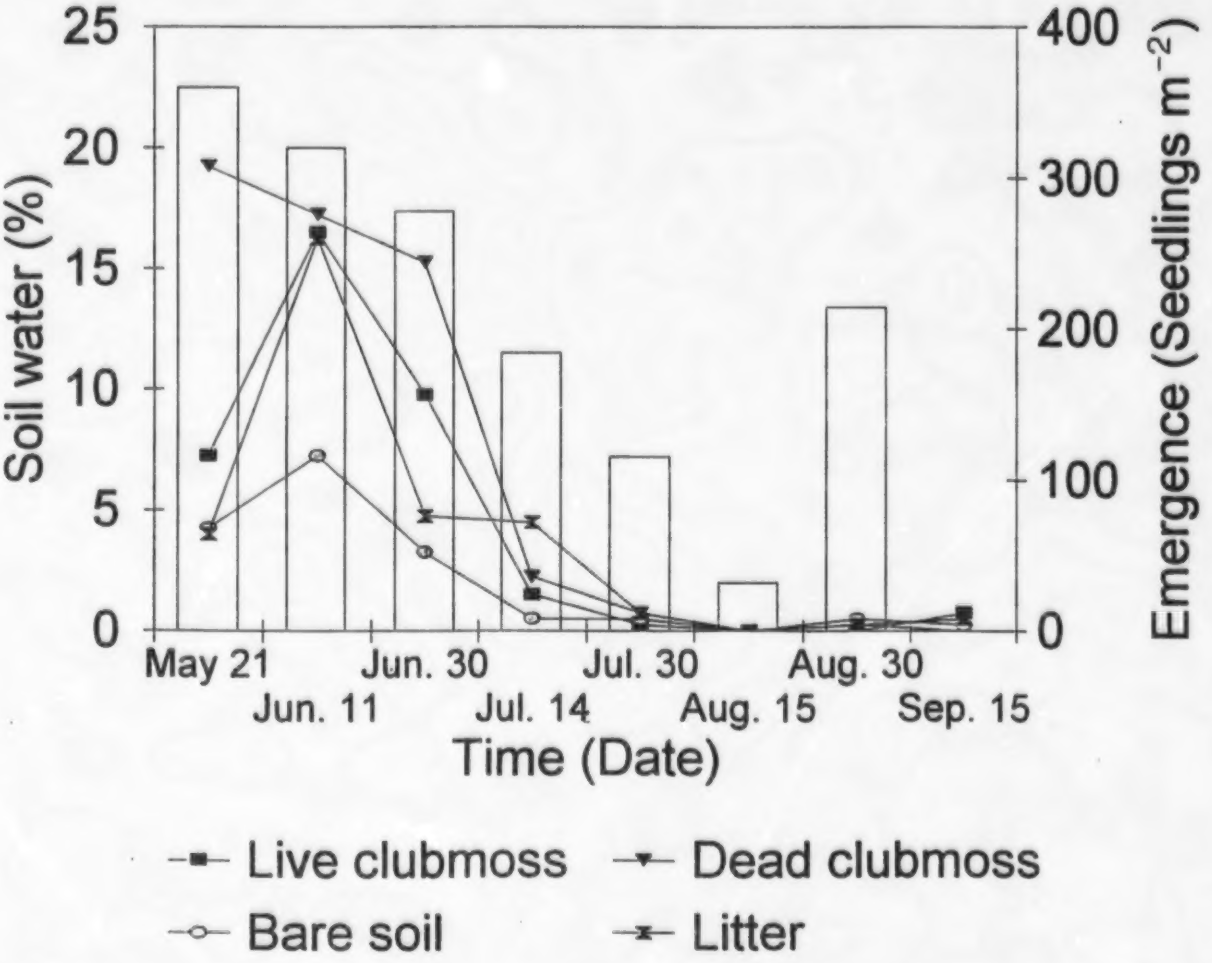

Figure 1. Emergence of grass seedlings within microsite types in relation to soil water at the 0-5 cm depth at Dundurn in 1997.

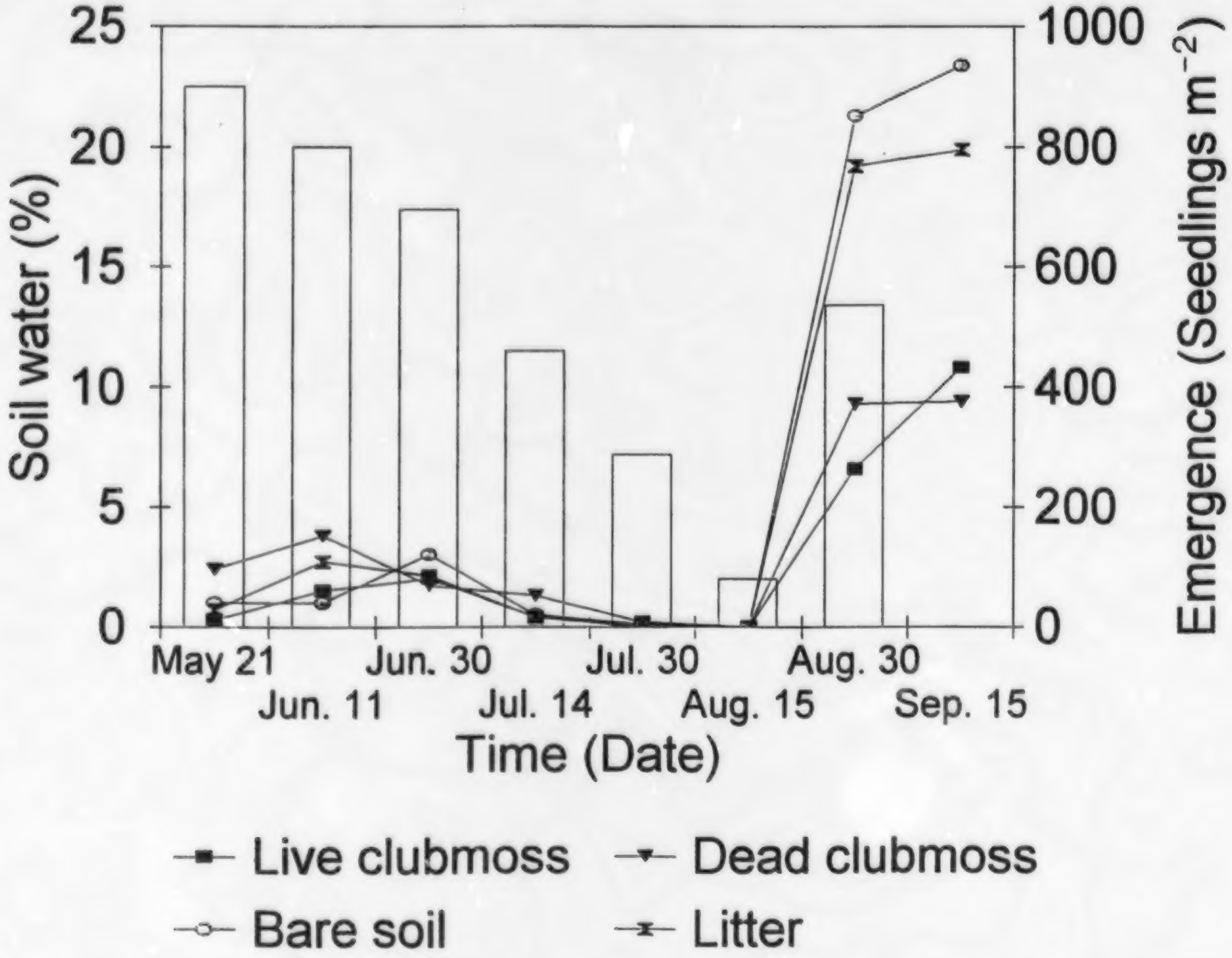

Figure 2. Emergence of forb seedlings within microsite types in relation to soil water at the 0-5 cm depth at Dundurn in 1997.

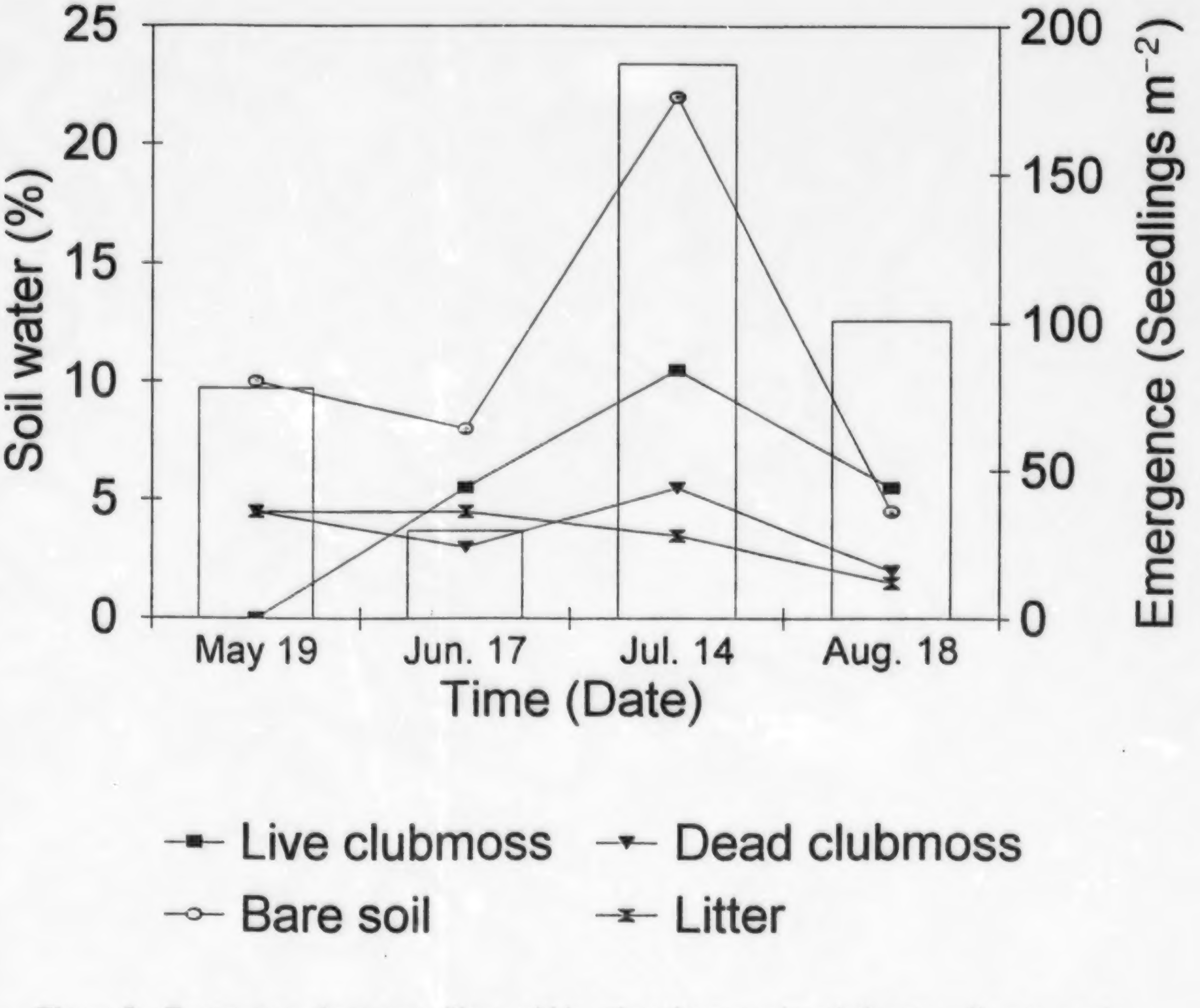

Figure 3. Emergence of grass seedlings within microsite types in relation to soil water at the 0-5 cm depth at Dundurn in 1998.

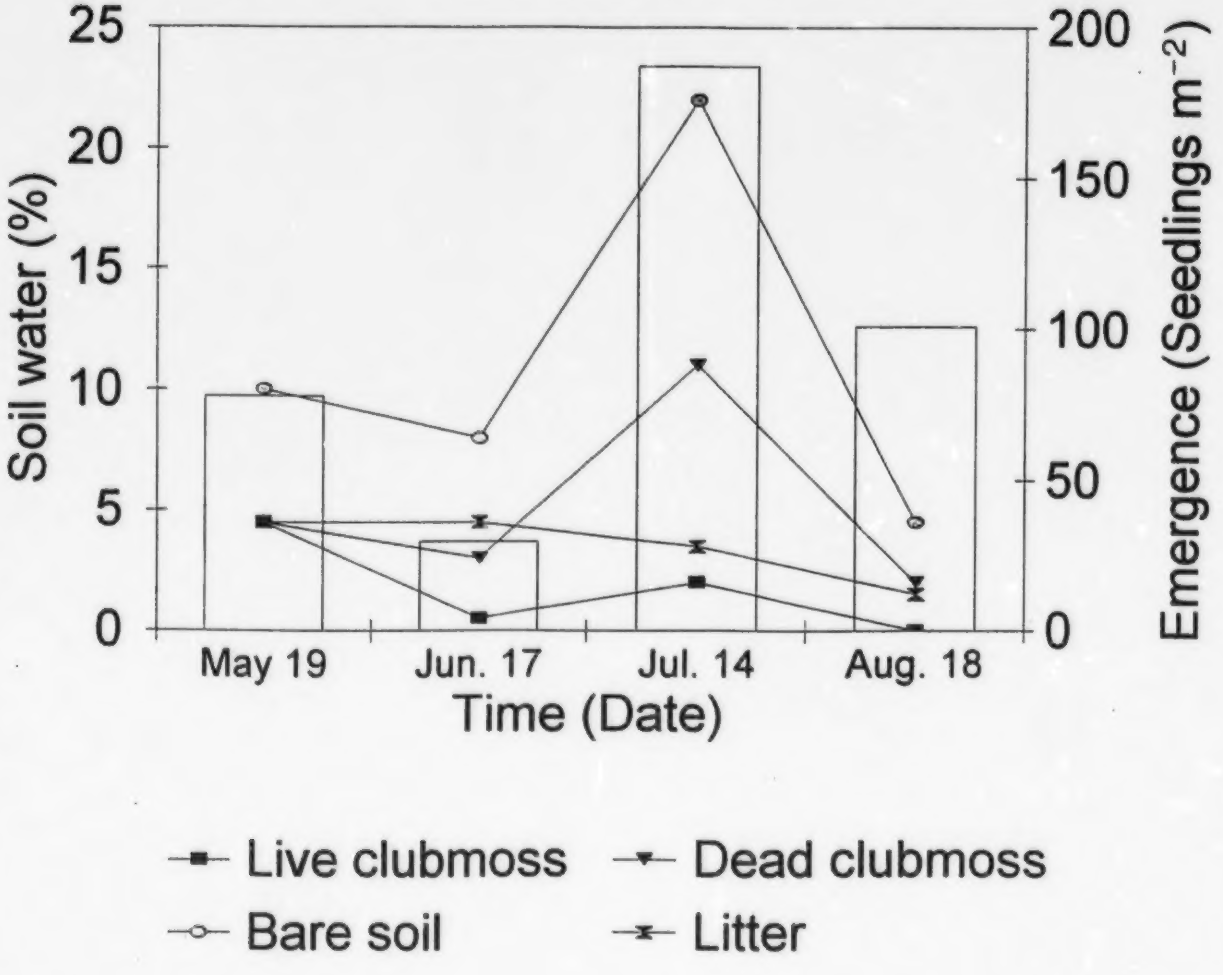

Figure 4. Emergence of forb seedlings within microsite types in relation to soil water at the 0-5 cm depth at Dundurn in 1998.

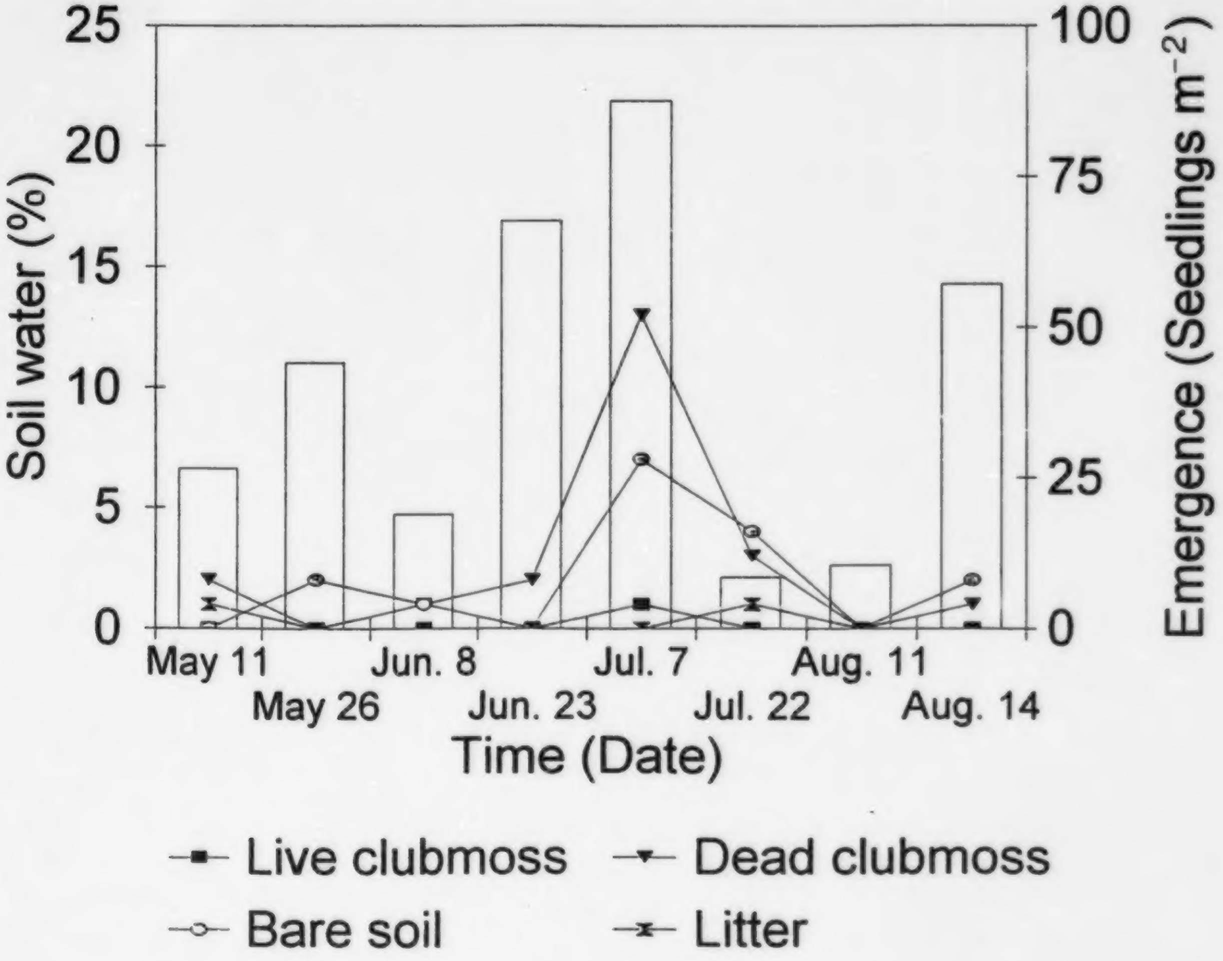

Figure 5. Emergence of grass seedlings within microsite types in relation to soil water at the 0-5 cm depth at Rudy in 1998.

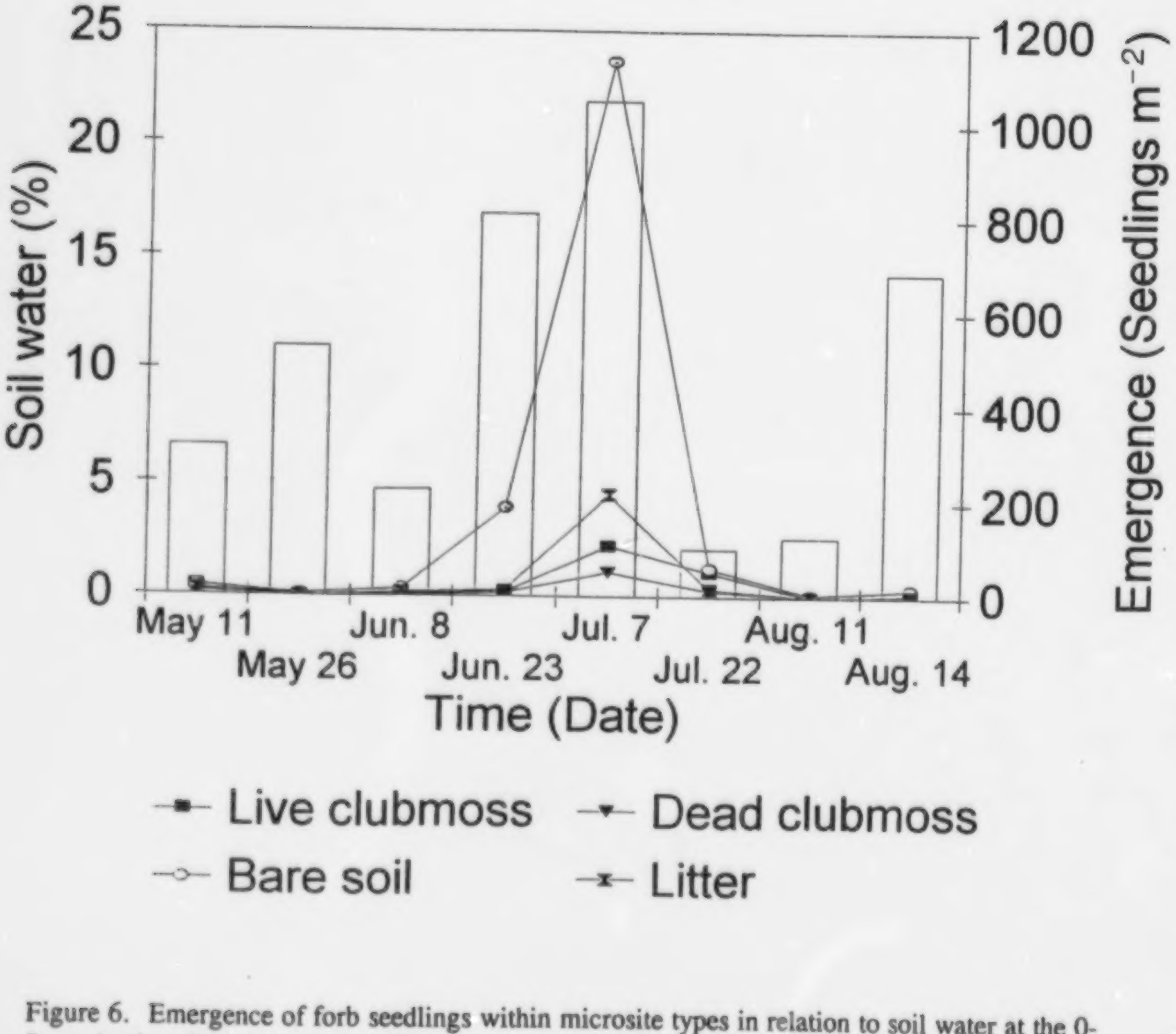

Figure 6. Emergence of forb seedlings within microsite types in relation to soil water at the 0-5 cm depth at Rudy during in 1998.

Table 3. Total emergence and survival of grass and forb seedlings at Dundurn from May-August 1997.

Precipitation treatment	Seedbed treatment			
	Control	Clubmoss killed	Clubmoss removed	Mean
	Emergence (seedlings m^{-2})			
Irrigated	293	494	460	415.7a[1]
Reduced	87	31	13	43.7c
Control	205	175	375	251.7b
Mean	195.0	233.3	282.7	237.0
	Survival (seedlings m^{-2})			
Irrigated	111	26	22	53.0a
Reduced	15	4	0	6.3c
Control	46	25	3	24.7b
Mean	57.3a	18.3b	8.3b	28.0

[1] Within survey dates means followed by similar letters or with no letters within a column or row are not significantly different ($P \leq 0.05$).

Table 4. The total number of grass and forb seedlings that emerged from different microsites at Dundurn in 1997.

Microsite	Number of seedlings observed [ab]	Number of seedlings greater than expected, less than expected, or proportional to availability of microsites [c]
	Grasses	
Live clubmoss	**576**	>Expected
Dead clubmoss	**880**	>Expected
Bare soil	**264**	<Expected
Litter	**496**	Proportional to availability
Total	**2,216**	
	Forbs	
Live clubmoss	**86**	<Expected
Dead clubmoss	**1,124**	<Expected
Bare soil	**2,012**	>Expected
Litter	**1,804**	>Expected
Total	**5,804**	

[a] Proportion of total ground cover is 0.16 for live clubmoss, 0.29 for dead clubmoss, 0.32 for bare soil and 0.23 for litter. Values represent expected seedling observations if seedlings occurred in each microsite in exact proportion to availability.

[b] Within dates bold numbers indicate total number of observed seedlings emerging in microsites was significantly different than random at $X^2_{0.05,3} = 7.4$.

[c] >Expected, <Expected, and Proportional to availability of microsite types determined from Bonferroni Confidence Intervals ($P \leq 0.05$).

Table 5. The total number of grass and forb seedlings that survived in different microsites at Dundurn in 1997. Survival was determined on 30 August 1997.

Microsite	Number of seedlings observed[ab]	Number of seedling greater than expected, less than expected, or proportional to availability of microsites[c]
	Grasses	
Live clubmoss	**240**	>Expected
Dead clubmoss	**440**	>Expected
Bare soil	**76**	<Expected
Litter	**148**	<Expected
Total	**904**	
	Forbs	
Live clubmoss	**8**	Proportional to availability
Dead clubmoss	**36**	Proportional to availability
Bare soil	**12**	<Expected
Litter	**24**	Proportional to availability
Total	**80**	

[a] Proportion of total ground cover is 0.16 for live clubmoss, 0.29 for dead clubmoss, 0.32 for bare soil and 0.23 for litter. Values represent expected seedling observations if seedlings occurred in each microsite in exact proportion to availability.

[b] Within dates bold numbers indicate total number of observed seedlings emerging in microsites was significantly different than random at $X^2_{0.05,3} = 7.4$.

[c] >Expected, <Expected, and Proportional to availability of microsite types determined from Bonferroni Confidence Intervals ($P \leq 0.05$).

Table 6. Total emergence and survival of grass and forb seedlings at Dundurn from May-August 1998.

Precipitation treatment	Seedbed treatment			
	Control	Clubmoss killed	Clubmoss removed	Mean
	Emergence (seedlings m^{-2})			
Irrigated	9.5	14.3	14.2	12.7a[1]
Reduced	5.4	6.8	10.1	7.4b
Control	3.9	6.5	8.0	6.1b
Mean	6.3b	9.2a	10.8a	8.7
	Survival (seedlings m^{-2})			
Irrigated	4.7	7.7	8.4	6.9a
Reduced	3.5	4.4	4.9	4.3b
Control	2.8	3.9	3.5	3.4b
Mean	3.7	5.3	5.6	4.9

[1] Within survey dates means followed by similar letters or with no letters within a column or row are not significantly different ($P \leq 0.05$).

Table 7. The total number of grass and forb seedlings that emerged from different microsites at Dundurn in 1998.

Microsite	Number of seedlings observed[a,b]	Number of seedlings greater than expected, less than expected, or proportional to availability of microsites[c]
	Grasses	
Live clubmoss	56	<Expected
Dead clubmoss	164	<Expected
Bare soil	356	>Expected
Litter	112	<Expected
Total	688	
	Forbs	
Live clubmoss	172	Proportion to availability
Dead clubmoss	164	<Expected
Bare soil	356	>Expected
Litter	112	<Expected
Total	804	

[a] Proportion of total ground cover is 0.20 for live clubmoss, 0.31 for dead clubmoss, 0.17 for bare soil and 0.25 for litter. Values represent expected seedling observations if seedlings occurred in each microsite in exact proportion to availability.

[b] Within dates bold numbers indicate total number of observed seedlings emerging in microsites was significantly different than random at $X^2_{0.05,3} = 7.4$.

[c] >Expected, <Expected, and Proportional to availability of microsite types determined from Bonferroni Confidence Intervals ($P \leq 0.05$).

Table 8. The total number of grass and forb seedlings that survived in different microsites at Dundurn in 1998.

Microsite	Number of seedlings observed[ab]	Number of seedlings greater than expected, less than expected, or proportional to availability of microsites[c]
	Grasses	
Live clubmoss	**8**	Proportional to availability
Dead clubmoss	**20**	>Expected
Bare soil	**4**	Proportional to availability
Litter	**0**	<Expected
Total		
	Forbs	
Live clubmoss	**48**	Proportional to availability
Dead clubmoss	**48**	<Expected
Bare soil	**76**	>Expected
Litter	**24**	<Expected
Total	**196**	

[a] Proportion of total ground cover is 0.20 for live clubmoss, 0.31 for dead clubmoss, 0.17 for bare soil and 0.25 for litter. Values represent expected seedling observations if seedlings occurred in each microsite in exact proportion to availability.

[b] Within dates bold numbers indicate total number of observed seedlings emerging in microsites was significantly different than random at $X^2_{0.05,3} = 7.4$.

[c] >Expected, <Expected, and Proportional to availability of microsite types determined from Bonferroni Confidence Intervals ($P \leq 0.05$).

Table 9. Total emergence and survival of grass and forb seedlings at Rudy from May-August 1998.

Precipitation treatment	Seedbed treatment			
	Control	Clubmoss Killed	Clubmoss removed	Mean
	Emergence (seedlings m^{-2})			
Irrigated	225bc[1]	273bc	1178a	558.7
Reduced	65cd	40cd	55d	53.3
Control	31cd	155bcd	566b	250.7
Mean	107.0	156.0	599.7	287.6
	Survival (seedlings m^{-2})			
Irrigated	5	6	17	9.3
Reduced	5	0	5	3.3
Control	1	5	0	2.0
Mean	3.7	3.7	7.3	4.9

[1] Within survey dates means followed by similar letters or with no letters within a column or row are not significantly different ($P \leq 0.05$).

Table 10. The total number of grass and forb seedlings that emerged from different microsites at Rudy in 1998.

Microsite	Number of seedlings observed[ab]	Number of seedlings greater than expected, less than expected, or proportional to availability of microsites[c]
	Grasses	
Live clubmoss	**4**	<Expected
Dead clubmoss	**88**	>Expected
Bare soil	**64**	>Expected
Litter	**8**	<Expected
Total	**164**	
	Forbs	
Live clubmoss	**188**	<Expected
Dead clubmoss	**88**	<Expected
Bare soil	**1,444**	>Expected
Litter	**268**	<Expected
Total	**1,988**	

[a] Proportion of total ground cover is 0.19 for live clubmoss, 0.25 for dead clubmoss, 0.24 for bare soil and 0.27 for litter. Values represent expected seedling observations if seedlings occurred in each microsite in exact proportion to availability.

[b] Within dates bold numbers indicate total number of observed seedlings emerging in microsites was significantly different than random at $X^2_{0.05,3} = 7.4$.

[c] >Expected, <Expected, and Proportional to availability of microsite types determined from Bonferroni Confidence Intervals ($P \leq 0.05$).

Table 11. The total number of grass and forb seedlings that survived in different microsites at Rudy in 1998.

Microsite	Number of seedlings observed[a,b]	Number of seedlings greater than expected, less than expected, or proportional to availability of microsites[c]
	Grasses	
Live clubmoss	0	–[d]
Dead clubmoss	0	–
Bare soil	4	–
Litter	0	–
Total	4	
	Forbs	
Live clubmoss	0	<Expected
Dead clubmoss	0	<Expected
Bare soil	20	>Expected
Litter	4	Proportional to availability
Total	24	

[a] Proportion of total ground cover is 0.19 for live clubmoss, 0.25 for dead clubmoss, 0.24 for bare soil and 0.27 for litter. Values represent expected seedling observations if seedlings occurred in each microsite in exact proportion to availability.

[b] Within dates bold numbers indicate total number of observed seedlings emerging in microsites was significantly different than random at $X^2_{0.05,3} = 7.4$.

[c] >Expected, <Expected, and Proportional to availability of microsite types determined from Bonferroni Confidence Intervals ($P \leq 0.05$).

[d] Bonferroni test not conducted because X^2 was not significant ($P > 0.05$).

Discussion

Different seedbeds confer different probabilities of emergence and survival within and between species of plants. By modifying clubmoss, its effects on seedling emergence and survival were determined. Water may be the main factor limiting plant growth in Northern Mixed Prairie. Smoliak *et al.* (1982) suggested seedlings of native plants establish in clubmoss under above-average precipitation conditions, but rarely under dry conditions. By experimentally altering precipitation, the effects of precipitation on seedling emergence and survival were exposed.

Emergence of native seedlings is strongly limited by precipitation because in all cases emergence of seedlings was greatest when irrigated. In two of three years, survival of seedlings was also limited by precipitation while in one year survival was not affected by precipitation or seedbed conditions. As in other semiarid ecosystems (Frasier 1992), precipitation appears to place major restrictions on emergence of seedlings in Northern Mixed Prairie. Adequate soil water is essential for emerging seedlings to develop root systems capable of supporting plants during later periods of drought (Frasier *et al.* 1984). Not surprisingly, seedling survival in the present study was favored by irrigation.

When emergence and survival of seedlings from clubmoss is considered separately for grasses and forbs, a complex picture emerges. In one year emergence and survival of grass seedlings was favored by clubmoss. In another year clubmoss reduced emergence of grass seedlings, but seedling survival was unaffected or enhanced by clubmoss. Yet in another year, emergence of grass seedlings was favored or reduced, but clubmoss had no influence on survival. Emergence of forbs was reduced by clubmoss, but survival was unaffected in one year, but in another year emergence and survival were reduced or unaffected by clubmoss. In another year emergence and survival of forbs were reduced by clubmoss.

Given this complex of interaction among plant groups, seedbed characteristics, and year, it is concluded that categorical statements about beneficial, neutral, or negative effects of clubmoss on emergence and survival of native grasses and forbs do not apply. Instead, clubmoss can affect emergence and survival of native grasses and forbs in all ways depending on site and year. Furthermore, the issue is complicated by the fact that different cohorts respond to clubmoss in unique ways. Therefore it is concluded that predictability of clubmoss effects on seedling dynamics is further modified by time of seedling emergence and environmental influences. Site conditions, timing, frequency and intensity of precipitation, and other environmental factors likely interact to illicit unique seedling emergence and survival.

In summary the hypotheses that limited precipitation restricts emergence of seedlings is accepted. However, because no consistent effects of clubmoss on seedling emergence and survival were observed, the hypothesis that clubmoss has negative effects on seedling dynamics is rejected. Alternatively, the hypothesis that site and environmental conditions limit emergence and establishment more than clubmoss is proposed. Evidence from these studies suggest environmental conditions, specifically water, place greater restrictions on seedling emergence and survival than clubmoss and the restrictions are unique to individual cohorts of seedlings. Provided seeds are present in the soil seedbank, management activities that improve the water balance on a site appear more important in promoting seedling establishment of perennial grasses and forbs than activities that are designed to reduce cover of clubmoss.

Soil Seedbank Reserves-Clubmoss Relations On Mixed Prairie

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Abstract

In Saskatchewan many range managers have suggested that range condition declines on grazed rangeland because clubmoss (*Selaginella densa*) inhibits establishment of desirable species. Data are apparently not available to allow one to accept or reject this hypothesis. It is possible that recruitment of desirable species may be seed limited and not limited by clubmoss. The purpose of this study was to test the hypothesis that recruitment of desirable plants in rangeland with clubmoss is seed limited. Relationships between clubmoss cover and range condition score and the number of seeds and species composition of the soil seedbank were evaluated on 100 pastures in Mixed Prairie in the Brown Soil Zone of southern Saskatchewan. Of the 100 pastures sampled, 71 were classed as Loamy range sites, 19 were Thin range sites, and 10 were Sands-Sandy range sites. On average 27% of the pastures were in poor condition, 69% were in fair condition, and 4% were in good condition. Depending on range site, clubmoss cover of soil ranged from 3 to 63%; averaged across range sites clubmoss cover was 27, 22, and 14% on poor, fair, and good condition range, respectively. Seedling densities emerging from soil samples tended to increase as range condition decreased, and ranged from 0 to nearly 5,300 seeds m^{-2}. Seedlings of increaser species were most common, followed by invader species; decreaser species were uncommon in the seedbank. *Koeleria cristata* and *Carex* sp. were most important among graminoids in the seedbank. *Androsace septentrionalis* and *Artemisia frigida* were the most important annual and perennial forbs, respectively. Because seed densities were generally not related to clubmoss cover and range condition score suggests that other factors such as climatic conditions and lack of seed production probably place greater control on seed reserves in the soil, and potential recruitment of new plants. When sites are disturbed to control clubmoss, a plant community dominated by early successional species (increasers and invaders) should be anticipated to develop from the seedbank. Under rare circumstances, substantial amounts of decreaser species may be present in the seedbank and they may colonize the site following mechanical disturbance. The hypothesis that seedling recruitment is limited by clubmoss is rejected. An alternative hypothesis that seedling recruitment of desirable species is seed limited rather than clubmoss limited is proposed.

Introduction

The principle reason for mechanically disturbing rangeland with high cover of clubmoss (*Selaginella densa*) is to increase forage production. Production may increase following disturbance because of enhanced growth of existing plants, new plants may be recruited, or both. Reliance on development of new plants assumes that seeds of desirable species are present in the soil seedbank. Generally substantial numbers of seeds of plants are present in soil on rangeland (Archibold 1981, Grilz and Romo 1995). In Fescue Prairie of Alberta, the number of seeds in the soil increased with grazing pressure, but early successional species dominated (Willms and Quinton 1995). Seed densities in the soil on Mixed Prairie in southern Alberta increased with grazing pressure, however, the proportion of early successional species also increased (Johnston *et al*. 1969).

In Saskatchewan many range managers have suggested that range condition declines on grazed rangeland because clubmoss inhibits establishment of desirable species. Establishment of perennial grasses and forbs appears to be limited by precipitation and not clubmoss (Junor and Romo 1998). The purpose of this study was to determine relationships between clubmoss cover and range condition score and the number of seeds and species composition of the soil seedbank on Mixed Prairie in the Brown Soil Zone of southern Saskatchewan.

Materials and Methods

In late September-early October 1997, 100 pastures were selected in the Brown Soil Zone of southern Saskatchewan. The Brown Soil Zone was selected for it has the most native grassland remaining in the Province, and it is in this soil zone in which many range managers perceive clubmoss as a management issue. Autumn was chosen for sampling because it is expected that seed reserves in the soil would be greatest at this time of the year. Sites were selected to provide a broad gradient in range condition, clubmoss cover, and managerial activity. Emphasis was also placed on selecting Loamy, Sands, Sandy, and Thin range sites (Abouguendia 1990) for they are the most common range sites in southern Saskatchewan. Sites that had been cultivated or were seeded to tame forages were not sampled.

After a site was selected, clubmoss cover was estimated in 2-0.5 X 0.5 m quadrats about 5 m apart. In the same quadrats, the proportion that each plant species contributed to total cover was visually estimated to the nearest 5%. Two-5.7cm diameter X 7.5 cm soil cores were collected from diagonal corners of each quadrat. Soil cores from the 2 quadrats were combined in 1 plastic bag and transported to the laboratory where they were air dried for about 3 months. The 4-191.5 cm^{-3} soil samples (total 766 cm^{-3} of soil) in each bag were mixed, split into 2 fractions, and each fraction was placed in a 12.5 X 12.5 X 5.0 cm tray. Soil samples were about 3 cm in thickness in the trays. Samples were watered and randomly placed in a growth chamber with 12 hours of darkness at 8°C and 12 hours light (220 $\mu mol\ m^{-2}\ s^{-1}$) at 20°C. Emergence was nearly nil after about 30 days, but the samples were incubated for a total of 60 days. Soil samples were kept moist by watering at 1- to 2-day intervals, and seedlings were identified and removed at about 14-day intervals.

Legal land descriptions were recorded for each site, and they were used to determine soil taxonomic units and soil texture from soil surveys completed by the Saskatchewan Soil Survey. Range sites were then determined and range condition calculated as described by Abouguendia (1990) after species composition data were averaged for the 2 quadrats for each site. Cover of clubmoss was also averaged for the 2 quadrats at each site. Species density, species frequency, and the proportion of the total number of seeds emerging were compiled for the soil sample from each site. An importance value was calculated for each species by multiplying species frequency by proportion of the total seedbank. Seed density of annual forbs, perennial forbs, perennial grasses, introduced forbs and grasses, all species, decreasers, increasers, and invaders (Abouguendia 1990) were then regressed (Snedecor and Cochran 1980) against cover of clubmoss and range condition score. Regression analysis was further used to examine relationships between cover of graminoids, forbs, all species combined and the density of seeds in the soil seedbank for the 3 groups. Percent of total seeds that were decreasers, increasers, or invaders were regressed on condition score. Clubmoss cover was also regressed on cover of graminoids, forbs and total cover. In all regression analyses, relationships were determined for each of the 3 range sites, and for all sites combined. Statistical significance was assumed at $P \leq 0.01$.

Results and Discussion

Of the 100 pastures sampled, 71 were classed as Loamy range sites, 19 were Thin range sites, and 10 were Sands-Sandy range sites (Table 1). Averaged across sites, 27% were in poor condition, 69% were in fair condition, 4% were in good condition, and none were in excellent condition. Range condition score for all sites combined averaged 32 or low fair. The estimated 96% of the pastures sampled in the Brown Soil Zone classed as being in poor or fair ecological condition is greater than the estimate of 75% of native range being in the same range condition (Zhang and Romo 1994).

Except for Sands-Sandy range sites where clubmoss cover tended to increase with range condition, clubmoss cover decreased as range condition increased (Table 1). Cover of clubmoss was negatively related to cover of graminoids and forbs, and total plant cover, with the strongest relationship occurring between clubmoss cover and total plant cover (Table 2). For each percent increase in graminoid, forb, and total plant cover, clubmoss cover decreased 0.3, 0.3 and 0.7%, respectively. Because coefficients of determination (R^2) ranged from 0.04 to 0.40 suggests that factors in addition to plant cover influence cover of clubmoss. It appears that management which is not designed to maintain plant cover encourages an increase in cover of clubmoss. This conclusion is supported by Abouguendia's (1990) assertion that clubmoss is an increaser under improper grazing management.

Total seedling densities tended to decrease as range condition increased (Table 3). Averaged across all sites, seedling densities were about 1.3 times greater in poor than fair condition sites, 2.2 fold higher in fair than good sites, and 1.7 times more in fair than good condition range. Variation in seedling densities was extremely high, ranging from 0 to nearly 5,300 seeds m^{-2}. These seedling densities are similar to the seed densities of 1,300 to 6,500 seeds m^{-2} in seed rain in Mixed Prairie in southern Saskatchewan (Clark 1997). In the present study seedlings of increaser species were most common, followed by invaders; decreaser species were uncommon in the seedbank, contributing 0 to 13% of the seedlings. In low condition range in Mixed and Fescue Prairies, increaser and invader species were more common in the seedbank that late seral species (Johnston *et al.* 1969, Willms and Quinton 1995).

Forty-two species emerging from soil samples were identified; in addition 4 unknown forb species also emerged (Table 4). Species richness in seed rain in Mixed Prairie ranged from 27 to 41 species, depending on year and site (Clark 1997). Of the 11 native, C_3 graminoids emerging from soil samples, *Koeleria cristata* was most abundant, followed by *Carex* sp., *Poa secunda* and *Stipa comata*. *Bouteloua gracilis* was most abundant of the 2 native, C_4 graminoids. *Poa pratensis* was the only introduced graminoid that emerged. *Androsace septentrionalis* was most abundant of the 5 native, C_3 annual forbs. *Artemisia biennis* was the only native, C_3 biennial forb. Thirteen native C_3, perennial forbs emerged with *Artemisia frigida* most common. *Descurainia sophia* was most abundant of introduced, C_3 annual forbs, while *Melilotus officinalis* was the most common introduced, C_3 biennial forb. *Descurainia sophia* was most abundant of introduced, annual forbs in Fescue Prairie of Saskatchewan (Grilz and Romo 1995). *Taraxacum officinale* and *Amaranthus retroflexus* were the only introduced, C_3 perennial and C_4 annual forbs, respectively. No shrubs emerged from soil samples.

When importance values were considered for all species, *Koeleria cristata* and *Carex* sp. were most important among graminoids emerging from the seedbank (Table 5). *Koeleria cristata* was 1 of the more abundant perennial grasses in soils of Mixed Prairie in Alberta, but Carex sp. were not present in the soil seedbank (Johnston *et al.* 1969). *Androsace septentrionalis* and *Artemisia frigida* were the most important annual and perennial forbs, respectively. These forbs were most abundant in Fescue Prairie (Archibold 1981; Grilz and Romo 1995, Willms and Quinton 1995) whereas *Artemisia frigida* was the second most abundant forb in Mixed Prairie (Johnston *et al.* 1969).

With the exception of annual forbs on Thin range sites, and introduced forbs on Sands-sandy range sites, seedling densities were not related to clubmoss cover (Table 6). On Thin range sites annual forbs increased as clubmoss cover increased while density of introduced forbs and graminoids decreased as clubmoss cover increased.

As range condition score increased, seed density of annual forbs decreased on Thin, Sands-Sandy and all range sites combined (Table 7). Density of perennial forbs emerging from the seedbank increased as range condition score increased on Sands-Sandy range sites.

Density of perennial grasses, perennial forbs and total seedlings emerging was not related to cover percentages for the same groups (Table 8). Clark (1997) also reported that species composition of the sward and seed production were not closely related. The proportion of seedlings emerging from the seedbank that was decreasers, increasers or invader species was not related to range conditions scores.

Seed densities were within the range reported for Mixed Prairie in Alberta (Johnston *et al.* 1969) and Fescue Prairie (Archibold 1981, Grilz and Romo 1995, Willms and Quinton 1985). As in the present study reductions in seed densities with increasing range condition were reported by Johnston *et al.* (1969) and Willms and Quinton (1985). That seed densities were generally not related to clubmoss cover and range condition score suggests that other factors such as climatic conditions and lack of seed production probably place greater control on seed reserves in the soil. It is likely that seed production by plants dictates seed reserves in the soil which in turn in controlled by patterns of precipitation (Clark 1997) and vigor of plants. It is also possible that predation on seeds or loss of seed through decay may reduce seed reserves. Despite greater numbers of seedlings emerging from soils on lower condition range, the seedbank was dominated by early to mid-successional species. Density of species that are classed as decreasers was, however, minimal. Therefore, when sites are disturbed to control clubmoss, a plant community dominated by early successional species (increasers and invaders) should be anticipated to develop.

Conclusions

Generally many seedlings emerged from the soil seedbank in the 100 range sites sampled. Most of the species emerging were, however, early successional species. The hypothesis that clubmoss limits recruitment of desirable or late successional range plants is therefore rejected. This rejection of the hypothesis is supported by Junor and Romo's (1998) findings that precipitation places greater control on seedling emergence and survival than clubmoss. Alternatively, it is hypothesized that regeneration of desirable plants is seed limited on rangeland with high amounts of clubmoss cover. It is possible, however, that under some circumstances, substantial amounts of decreaser species may be present in the seedbank and they may colonize the site following mechanical disturbance. Because few decreaser species emerged from the soil seedbank, it is recommended that soil samples be collected and a bioassay of seedbank composition determined before disturbing range. Knowledge gained from this assay will increase the predictability of which species may increase in the plant community before attempting to control clubmoss. More importantly, it may be advisable to first evaluate management to ensure that desirable species are producing seeds, favorable conditions are present for seedling establishment, and that favorable conditions for the expansion of clubmoss cover are not being created. After this evaluation is completed, the issue of whether to focus management efforts on clubmoss or other aspects of range management can be rationalized. Management that is flexible and can take advantage of applying clubmoss control methods after large amounts of desired species produce seeds is recommended over management strategies which do recognize the importance of seed production of preferred plant species.

Table 1. Range sites, range condition scores, number of sites per range condition class, mean range condition score, mean clubmoss cover, and range of clubmoss cover for 100 range sites sampled in southern Saskatchewan.

Range site	Range condition (Class)[1]	Sites (Number)	Mean range condition (Score)	Mean clubmoss cover (%)	Range in clubmoss cover (%)
Loamy	Poor	19	19	27	3-63
	Fair	51	35	22	3-48
	Good	1	58	13	13
Thin	Poor	6	19	33	13-53
	Fair	12	35	24	10-38
	Good	1	63	13	13
Sands-sandy	Poor	2	19	14	10-18
	Fair	6	36	16	3-28
	Good	2	60	17	13-20
All sites	Poor	27	19	27	3-63
	Fair	69	35	22	3-48
	Good	4	60	14	13-20

[1] No range sites in excellent condition were sampled.

Table 2. Relationships between cover of clubmoss (Y, %) and cover of graminoids, perennial forbs, and total plant cover (X, %) averaged over the 100 range sites sampled in southern Saskatchewan.

Predictor (X)	Regression equation	R^2	P
Graminoid cover (%)	Y=38-0.3X	0.15	0.000
Forb cover (%)	Y=26-0.3X	0.04	0.054
Total plant cover (%)	Y=66-0.7X	0.40	0.000

Table 3. Range sites, range condition, mean number of seedlings m^{-2}, range in the number of seedlings, and the percentage of all seedlings that were decreasers, increasers or invaders. Soils were from the upper 7.5 cm of the soil profile and they were incubated in the laboratory.

Range site	Range condition (class) [1]	Mean (seedlings m^{-2})	Range (seedlings m^{-2})	Decreasers (%)	Increasers (%)	Invaders (%)
Loamy	Poor	1836	196-4,312	6	76	18
	Fair	1522	196-5,096	8	71	21
	Good	1372	1,372	0	100	0
Thin	Poor	1405	588-2,744	6	90	4
	Fair	1470	0-3,528	10	79	11
	Good	0.0	--	--	--	--
Sands-sandy	Poor	4704	4,366-5,292	0	50	50
	Fair	1078	392-2,548	7	65	28
	Good	1078	784-1,372	13	61	26
All sites	Poor	1953	196-5,292	6	77	17
	Fair	1475	0-5,096	9	71	20
	Good	882	0-1,372	8	74	18

[1] None of the range sites sampled were in excellent condition.

Table 4. Species origin, photosynthetic pathway, lifeform, plant species, frequency, the proportion of seeds that each species contributed to all seedlings germinating in soil seedbank samples from the upper 7.5 cm of the soil profile. Values are averaged over all range sites.

Origin	Photosynthetic pathway	Lifeform	Species	Frequency (%)	Proportion (% of total)
Native	C_3	Graminoids	*Agropyron dasystachyum*	1	1.1
			Agropyron smithii	7	1.1
			Agropyron trachycaulum	1	0.1
			Carex sp.	39	10.9
			Hordeum jubatum	4	0.5
			Koeleria cristata	65	37.1
			Oryzopsis hymenoides	5	0.8
			Poa secunda	15	2.8
			Stipa comata	15	2.7
			Stipa curtiseta	2	0.3
			Stipa viridula	8	1.3
Native	C_4	Graminoids	*Bouteloua gracilis*	11	1.6
			Sporobolus cryptandrus	1	0.3
Introduced	C_3	Graminoids	*Poa pratensis*	7	1.2
Native	C_3	Annual forbs	*Androsace septentrionalis*	62	12.7
			Monolepis nuttalliana	7	1.5
			Gnaphalium palustre	1	0.1
			Euphorbia serpyllifolia	1	0.1
			Solanum triflorum	1	0.3
Native	C_3	Biennial forb	*Artemisia biennis*	1	0.1
Native	C_3	Perennial forbs	*Artemisia frigida*	45	13.4
			Astragalus missouriensis	1	0.1
			Astragalus pectinatus	1	0.1
			Chrysopsis villosa	2	0.3
			Cirsium sp.	1	0.1
			Eriogonum flavum	4	0.6
			Haplopappus spinulosus	3	0.4
			Lesquerella ludoviciana	1	0.1
			Penstemon sp.	1	0.1
			Potentilla sp.	1	0.5
			Psoralea argophylla	2	0.3
			Ratibida columnifera	4	0.5
			Solidago sp.	1	0.1
Introduced	C_3	Annual forbs	*Chenopodium album*	1	0.1
			Crepis tectorum	1	0.1
			Descurainia sophia	15	2.5
			Lappula echinata	8	2.4
			Polygonum convolvulus	2	0.4
Introduced	C_3	Biennial forbs	*Melilotus officinalis*	1	0.3
			Tragopogon dubius	1	0.1
Introduced	C_3	Perennial forbs	*Taraxacum officinale*	2	0.3
Introduced	C_4	Annual forb	*Amaranthus retroflexus*	6	1.1
Unknown	Unknown	Forb	*Unknown*	4	0.1

Table 5. Relative importance values for plant species emerging in soil seedbank samples from the upper 7.5 cm of the soil profile. Importance values were calculated from multiplying species frequency by proportion of the total seed bank (See Table 2) for each species. Values are averaged over all range sites.

Species	Relative importance value
Koeleria cristata	100
Androsace septentrionalis	32.6
Artemisia frigida	25.0
Carex sp.	17.6
Poa secunda	1.7
Stipa comata	1.7
Descurainia sophia	1.6
Lappula echinata	0.8
Bouteloua gracilis	0.7
Monolepis nuttalliana	0.4
Stipa viridula	0.4
Poa pratensis	0.3
Agropyron smithii	0.3
Amaranthus retroflexus	0.3
Oryzopsis hymenoides	0.2
Eriogonum flavum	0.2
Hordeum jubatum	0.08
Ratibida columnifera	0.08
Haplopappus spinulosus	0.05
Agropyron dasystachyum	0.04
Polygonum convolvulus	0.03
Stipa curtiseta	0.02
Chrysopsis villosa	0.02
Psoralea argophylla	0.02
Taraxacum officinale	0.02
Potentilla sp.	0.02
Sporobolus cryptandrus	0.01
Solanum triflorum	0.01
Melilotus officinalis	0.01
Agropyron trachycaulum	<0.01
Gnaphalium palustre	<0.01
Euphorbia serpyllifolia	<0.01
Artemisia biennis	<0.01
Astragalus missouriensis	<0.01
Astragalus pectinatus	<0.01
Cirsium sp.	<0.01
Lesquerella ludoviciana	<0.01
Penstemon sp.	<0.01
Solidago sp.	<0.01
Chenopodium album	<0.01
Crepis tectorum	<0.01
Tragopogon dubius	<0.01
Unknown forbs	<0.01

Table 6. Regression equations, coefficients of determination, probability levels of significance for relationships between clubmoss cover (X, %) and seedling densities of different species groups (Y, seedlings m^{-2} in the upper 7.5 cm of the soil profile) on loamy, thin, sands-sandy range sites and all sites combined. Statistically significant ($P \leq 0.10$) regression equations are presented.

					Seedlings m^{-2}	
Range site	Species group	Regression equation	R^2	P	Mean	SE
Loamy	Annual forbs	--[1]	--	0.459	596	120
	Perennial forbs	--	--	0.234	453	75
	Perennial graminoids	--	--	0.311	1,761	205
	Decreasers	--	--	0.582	127	31
	Increasers	--	--	0.775	2,043	225
	Invaders	--	--	0.680	646	121
	Introduced forbs and graminoids	--	--	0.737	193	44
	All species			0.908	3,208	275
Thin	Annual forbs	$Y=24+9.4X$	0.23	0.036	536	121
	Perennial forbs	--	--	0.371	640	204
	Perennial graminoids	--	--	0.260	1,898	364
	Decreasers	--	--	0.624	330	193
	Increasers	--	--	0.857	2,187	366
	Invaders	--	--	0.198	227	62
	Introduced forbs and graminoids	--	--	0.894	124	52
	All species	--	--	0.622	2,744	486
Sands-Sandy	Annual forbs	--	--	0.823	1,215	667
	Perennial forbs	--	--	0.973	392	131
	Perennial graminoids	--	--	0.346	1,999	872
	Decreasers	--	--	0.798	196	105
	Increasers	--	--	0.361	2,117	829
	Invaders	--	--	0.904	1,294	656
	Introduced forbs and graminoids	$Y=245-10.5X$	0.42	0.044	157	97
	All species	--	--	0.513	3,606	1,061
All sites	Annual forbs	--	--	0.694	647	110
	Perennial forbs	--	--	0.802	482	67
	Perennial graminoids	--	--	0.974	1,811	181
	Decreasers	--	--	0.930	173	44
	Increasers	--	--	0.937	2,078	191
	Invaders	--	--	0.363	631	110
	Introduced forbs and graminoids	--	--	0.588	176	34
	All species	--	--	0.635	3,160	239

[1] – indicates regression equations were not significant ($P>0.10$)

Table 7. Regression equations, coefficients of determination, and probability levels of significance for relationships between range condition score (X) and seedling densities of different species groups (Y, seedlings m^{-2} in the upper 7.5 cm of the soil profile) on loamy, thin, sands-sandy range sites and all sites combined. Statistically significant ($P \leq 0.10$) regression equations are presented.

Range site	Species group	Regression equation	R^2	P
Loamy	Annual forbs	--[1]	--	0.912
	Perennial forbs	--	--	0.708
	Perennial graminoids	--	--	0.194
	Decreasers	--	--	0.520
	Increasers	--	--	0.373
	Invaders	--	--	0.832
	Introduced forbs and graminoids	--	--	0.758
	All species	--	--	0.371
Thin	Annual forbs	$Y=651-12.1X$	0.28	0.020
	Perennial forbs	--	--	0.554
	Perennial graminoids	--	--	0.954
	Decreasers	--	--	0.390
	Increasers	--	--	0.344
	Invaders	--	--	0.682
	Introduced forbs and graminoids	--	--	0.659
	All species	--	--	0.753
Sands-Sandy	Annual forbs	$Y=2{,}093-40.1X$	0.31	0.095
	Perennial forbs	$Y=-151+9.4X$	0.44	0.037
	Perennial graminoids	--	--	0.424
	Decreasers	--	--	0.238
	Increasers	--	--	0.470
	Invaders	--	--	0.115
	Introduced forbs and graminoids	--	--	0.720
	All species	--	--	0.151
All sites	Annual forbs	$Y=601-8.7X$	0.03	0.100
	Perennial forbs	--	--	0.731
	Perennial graminoids	--	--	0.144
	Decreasers	--	--	0.351
	Increasers	--	--	0.136
	Invaders	--	--	0.295
	Introduced forbs and graminoids	--	--	0.836
	All species	--	--	0.115

[1] – indicates regression equations were not significant ($P > 0.10$)

Table 8. Relationship between plant cover and seedling density of perennial grasses, perennial forbs, and total seedlings, and relationships between range condition score and percent of seedlings that were decreasers, increasers or invaders in soil samples.

Predictor (X)	Parameter (Y)[1]	P
Graminoid cover (%)	Seedling density of perennial grasses (no. m^{-2})	0.831
Forb cover (%)	Seedling density of perennial forbs (no. m^{-2})	0.214
Total cover (%)	Total seedling density (no. m^{-2})	0.249
Range condition score	Decreasers (% of total seedlings)	0.304
Range condition score	Increasers (% of total seedlings)	0.475
Range condition score	Invaders (% of total seedlings)	0.994

[1] Regression equations are not presented because they were not significant ($P > 0.10$).

Economic Analysis of Mechanically Disturbing Rangeland to Reduce Clubmoss and Increase Forage Production in Saskatchewan

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Abstract

The objective of this study was to complete an economic analysis of disking or chisel plowing, mechanical treatments that are commonly used to reduce clubmoss (*Selaginella densa* Rydb.) on rangelands in the Northern Great Plains. Cost and benefit analysis of disking or chisel plowing were determined for sandy and loamy range sites in the Dry and Moist Brown Soil Zones, and the Dark Brown Soil Zone in Saskatchewan by valuation of forage in terms of increased livestock production after treatment. Under best case scenarios, disking and chisel plowing increases forage yields and stocking rates on fair condition rangeland to levels similar to that in excellent condition. Economic feasibility of disking or chisel plowing depends upon treatment used, cost of treatment, forage production before treatment, increment of forage production after treatment, value of increased forage production, effective life of treatment, interest rate, and grazing deferment. All net present values for chisel plowing were negative, indicating this treatment is not economically feasible on any range site in all soil zones at either 8% or 10% interest rate. More than 30 years are required to recover costs of chisel plowing regardless of soil zone, range site, and discount rate. Economic feasibility of disking is greater than chisel plowing. Recovery of total costs of disking on a loamy range site occurred at 10 and 11 years post-treatment in the Dark Brown Soil Zone, 12 and 14 years in the Moist Brown Soil Zone, and 15 and 18 years in the Dry Brown Soil Zone at discount rates of 8 and 10%, respectively. At 8 and 10% discount rates respectively, 11 and 12 years are needed to recover costs of disking on sandy range sites in the Dark Brown Soil Zone, 13 and 15 years in the Moist Brown Soil Zone, and 17 and 24 years in the Dry Brown Soil Zone. It is questionable whether beneficial effects of disking or chisel plowing on herbage production exceed 10 years. Range managers considering disking or chisel plowing to reduce clubmoss on rangeland and improve forage productivity will find the net present value, internal rate of return, and the predicted number of years to break even useful in making economically prudent decisions.

Introduction

Many mechanical treatments have been developed for use on rangeland with the goal to alter clubmoss (*Selaginella densa* Rydb.) cover, increase herbage production, and change species composition on rangeland. Commonly used mechanical treatments in the Great Plains are pitting, furrowing, and ripping (Rauzi, 1974, 1975, Griffith *et al.* 1985). Because mechanical treatment removes ground cover, clubmoss is generally reduced or destroyed. Increases in forage production have been the primary criterion used to evaluate success of mechanical disturbances (Barnes *et al.* 1958, Lang 1958, Thomas and Young 1956). The longevity of treatment effects on forage production have ranged from 1 to 6 years, depending on location, climate, and treatment (Houston 1957, Barnes *et al.* 1958, Lang 1958, Lorenz and Rogler 1962, Houston 1963, Ryerson *et al.* 1968, Wight and White 1974, Rauzi 1974, 1975, White *et al.* 1981, Hart *et al.* 1985, White 1985). Despite increases in forage production following mechanical disturbance, weather is more important in determining forage productivity than mechanical disturbance (Haferkamp *et al.* 1993).

Whether mechanical disturbance of rangeland is economical remains undetermined. Economic analysis of mechanical disturbances on rangeland in Saskatchewan is needed to assist in making decisions regarding the utility of the practices. The objective of this study was to complete an economic analysis of pitting or chisel plowing, 2 mechanical treatments that are commonly used to reduce clubmoss on the Northern Great Plains. An economic model for Saskatchewan rangeland was established using published data on range pitting and chisel plowing. Analysis encompasses cost and benefit analysis of disking or chisel plowing for private rangeland on sandy and loamy range sites in the Dry Brown, Moist Brown, and Dark Brown Soil Zones in Saskatchewan.

Methods

Forage yield after mechanical treatment of clubmoss

Data from studies on the effects of mechanically disturbing rangeland to control clubmoss in Canada are lacking. Therefore, data from research (Ryerson *et al.* 1968) on pitting and chisel plowing near Havre and Malta, Montana were used in these analyses.

The pitting machine used was a modified, heavy breaking disk (Ryerson *et al.* 1968). This machine made pits about 76 cm long, 20 cm wide and 10 cm deep. About 45% of the ground surface was covered with pits and overturned sod. The pitted areas were not grazed for 2 years after treatment to allow vegetation to recover and new plants to establish. Pitting was done in the autumn, and plant yields were measured for 7 years. After the fifth year following treatment, herbage yields were similar to the untreated control. Yield varied from year-to-year, and on average, yield increases from pitting were greatest in years within higher precipitation. The ratio of herbage yield on pitted range to untreated control averaged 1.58, indicating a 58% increase in herbage yield.

A heavy duty cultivator was used for chisel plowing by plowing at 5-cm depth, followed by chisel plowing at a 10-cm depth at right angles, and finally, chisel plowing with 25-cm sweeps at 45° angles to the first treatment (Ryerson *et al.* 1968). Grazing was deferred for 2 years after treatment to allow vegetation to recover and establish. Yield of plants was determined 3 years after chisel plowing with average herbage yield 1.34 times greater than in control.

Estimated forage yields for range sites in Saskatchewan

Loamy and sandy range sites in dry areas of the Brown Soil Zone, moist areas in the Brown Soil Zone, and the Dark Brown Soil Zone (Abouguendia 1990) were selected for analysis of potential yield increases following mechanical disturbance of clubmoss. These range sites were selected because they are common in southern Saskatchewan, and are likely to be considered for mechanical disturbance. Forage yields were estimated from recommended stocking rates for Saskatchewan (Abouguendia 1990). Yields for untreated areas were computed using recommended stocking rates (Abouguendia 1990) for loamy and sandy range sites in fair condition in each soil zone. For example, the recommended stocking rate on a fair condition, loamy range site in the Dry Brown Soil Zone is 0.395 AUM/ha (Animal Unit Month). This stocking rate was multiplied by 354 kg/AUM, the amount of forage required by a 454 kg cow for 1 month. The calculated herbage yield was then divided by 55%, a proper use factor generally accepted on native range (Abouguendia, 1990). For example, (0.395 AUM/ha X 354 kg/AUM) / 0.55=254 kg/ha of forage. The amount of forage following treatment was then estimated by multiplying by the yield ratio of 1.58 and 1.34 for pitting and chisel plowing, respectively. For example, herbage yield is 254 kg/ha on fair condition range on a loamy range site in the Dry Brown Soil Zone, and predicted yield is 254 kg/ha X 1.58 = 401 kg/ha (Table 1). Herbage yield in the other soil zones and range sites were calculated the same way. In this analysis it was assumed that the 58 and 34% increase in herbage yield was constant over the life of the project and that 55% of the herbage produced could be grazed by cattle.

Estimated stocking rates and increases in stocking rate after pitting or chisel plowing clubmoss

The additional AUM increment produced by pitting or chisel plowing (Table 2) was calculated by: (Treated yield - Untreated yield) X 0.55 / 354 kg/AUM. For example, the potential increase in AUMs after pitting a loamy range site in the Dry Brown Soil Zone was calculated as:

$$(401 - 254) \times 0.55 / 354 \text{ kg/AUM} = 0.23 \text{AUM/ha}.$$

Potential stocking rates or stocking rates for excellent condition range (Abouguendia 1990) were used to check whether the predicted stocking rates for treated range were realistic. Stocking rates after pitting or chisel plowing were calculated by multiplying yield data following mechanical treatment by the proper use factor, and then dividing by 345 kg/ha. For example, stocking rate on pitted, loamy range site in dry areas of the Dry Brown Soil Zone is:

$$401 \times 0.55 / 345 = 0.64 \text{ AUM/ha}.$$

Except for sandy range sites in the Moist Brown Soil Zone, predicted stocking rates on treated range were similar to the potential stocking rates (Table 3).

Table 1. Predicted herbage yield after pitting or chisel plowing on loamy and sandy range sites in 3 soil zones in Saskatchewan, compared to published yields for the same range sites in fair range condition.

Treatment	Dry Brown		Moist Brown		Dark Brown	
	Loamy	Sandy	Loamy	Sandy	Loamy	Sandy
	Herbage yield (kg ha^{-1})					
Untreated[1]	254	206	349	302	460	413
Pitting	401	325	551	477	727	653
Chisel plowing	340	276	468	405	616	553

[1] Based on range sites in fair ecological condition *sensu* Abouguendia (1990).

Table 2. Estimated increases in stocking rates on loamy and sandy range sites in 3 soil zones expected after pitting or chisel plowing in Saskatchewan.

Treatment	Dry Brown		Moist Brown		Dark Brown	
	Loamy	Sandy	Loamy	Sandy	Loamy	Sandy
	Stocking rate (AUM ha^{-1})					
Pitting	0.23	0.19	0.32	0.28	0.43	0.38
Chisel plowing	0.14	0.11	0.19	0.16	0.25	0.22

Table 3. Recommend stocking rates of untreated range in excellent condition compared to predicted stocking rates on range in fair condition on loamy and sandy range sites in 3 soil zones in which pitting or chiseling was done in Saskatchewan.

Treatment	Dry Brown		Moist Brown		Dark Brown	
	Loamy	Sandy	Loamy	Sandy	Loamy	Sandy
	Stocking rate (AUM ha^{-1})					
Potential	0.61	0.49	0.86	0.74	1.11	0.98
Pitting	0.63	0.50	0.85	1.13	1.13	1.01
Chisel plowing	0.52	0.42	0.72	0.95	0.95	0.85

Economic analyses of mechanical disturbance on range

Framework and information used in analyses

When evaluating range improvements, a primary concern is to at least recover associated costs. Total cost incurred for treatment of clubmoss on range can be recovered by 1, a combination, or all of the following ways: 1) revenue received from increased red meat production; 2) increased sale or leasing value of range by improving the watershed, and increasing the forage production, and; 3) revenue from selling recreational privileges (Nielsen and Hinckley 1975). The first criterion was employed in this study.

Information required for economic analyses of treating clubmoss on range include: 1) cost of treatment; 2) original forage production; 3) expected increase in forage production; 4) expected value of increased forage production/AUM; 5) expected productive life of the improvement; 6) market interest rate or opportunity cost, and; 7) grazing deferment requirement (Nielsen and Hinckley 1975, Workman 1986).

Cost of treatment

Cost of pitting or chisel plowing clubmoss varies depending upon the kind of mechanical treatment used, type of equipment, difficulty of job, size of the area, and condition of area being treated. Other costs include operating and fixed costs, and grazing deferment.

Original forage production and predicted increase in forage production

The original forage production on a given range site must be known to calculate the cost of grazing deferment after treatment and the increase in forage production. Generally, 55% of forage is available for animal consumption and this value was considered in the economic evaluation. The predicted forage production is untreated yield minus yield after treatment times 55%. For example, if forage production increased by 400 kg/ha, 400 X 55% = 220 kg/ha is allocated for grazing.

Value of predicted increase in forage production per AUM

Determination of value of predicted increase in forage production per AUM is key in economic analysis. In this analysis, the annual economic return in terms of AUMs is calculated as follows: 1) Increased AUM/ha = increased forage production/345 kg/AUM; 2) Increased AU/ha = increased AUM/ha/month of grazing in a growing season; 3) Gain in AU/ha = increased AU/ha X days of grazing X average daily gain; 4) Benefit in AU/ha = Gain in AU/ha X value/kg, and 5) Profit in AUM/ha =(benefit in AU/ha - cost in AU/ha)/months of grazing

Expected productive life of treating range with clubmoss

The effective life of treating clubmoss depends upon the mechanical treatment used, range site, climate, and management practices. Longevity of treatment effects on forage production range from 1 to 6 years, depending on location, treatment, and climate (Houston 1957, Lorenz and Rogler 1962, Ryerson *et al.* 1968, Wight and White 1974, Rauzi 1974, 1975, White *et al.* 1981, Hart *et al.* 1985, White 1985). Until more information becomes available from long-term studies, beneficial effects of mechanical treatment on forage yield on rangeland should not be expected to exceed 10 years. Furthermore, given the lack of studies that are replicated, continuous, and long-term, analyses were completed at 5-year intervals to allow assessment for up to 30 years after treatment.

Market interest rate or opportunity cost of money

Market interest rate is the rate at which money can be borrowed or the best alternative use of capital will return. For practical purposes, the market rate of interest was assumed at 8% and 10%.

Determinants of economic feasibility of treating clubmoss on range

Three analysis techniques, net present value (NPV), benefit-cost ratio (BCR), and internal rate of return (IRR) were used to determine economic feasibility of treating clubmoss.

The usual procedure of net present value is to compare initial investment cost with the sum of discounted future net returns resulting from the investment. For a project to be economically feasible, net present value must be positive. The sum of discounted future return can be expressed mathematically as follows (***Equation 1***) (Workman 1986):

$$\mathrm{NPV} = \sum_{n=1}^{n} \left(\left(R_n - C_n \right) / \left(1+i \right)^n \right) \qquad \text{Eq. 1}$$

Where: R_n is gross benefit resulting from the investment
C_n is annual costs of the investment
i is discount rate
n is effective life of the project

The benefit-cost ratio is calculated by dividing present value of annual benefits resulting from investment by present value of initial investment cost. The benefit-cost ratio must be greater than 1 for the investment to be economically feasible. The mathematical formula is expressed as follows (***Equation 2***) (Workman 1986):

$$\mathrm{BCR} = \left(\sum_{n=1}^{n} \left(R_n / \left(1+i \right)^n \right) \right) / \left(\sum_{n=1}^{n} \left(C_n / \left(1+i \right)^n \right) \right) \qquad \text{Eq. 2}$$

Internal rate of return is the interest rate that discounts or forces a future stream of net returns to just equal the investment required to produce the flow of returns (Nielsen 1967). Projects are not economically feasible unless the internal rate of return is greater than the discount rate. The following formula (***Equation 3***) was used to calculate the internal rate of return (Nielsen 1967).

$$\mathrm{IRR} = \sum_{n=1}^{n} \left(R_n - C_n \right) / \left(1+i \right)^n \qquad \text{Eq. 3}$$

Costs and benefits are required to determine if pitting or chisel plowing clubmoss is economically feasible. Before analyzing costs and benefits, specific assumptions (Saskatchewan Agriculture and Food 1997) were required including: 1) Size of each range site in each area is 1000 ha; 2) Grazing is deferred 2 years after treatment of range; 3) The grazing season averages 3.5 months or 110 days; 4) Each cow gains 0.79 kg/day; 5) Average feeder price is \$2.25/kg; 6) Increased carrying capacity will last for 5, 10, 15, 20, 25, or 30 years after pitting or chisel plowing.

Costs

Costs considered in this analysis are only the changes after pitting or chisel plowing and vary with kind of machinery used, increment in animal carrying capacity, and years required for deferment. They include agricultural machinery costs, operation costs, and grazing deferment.

Machinery costs

Machinery costs for pitting or chisel plowing depend upon type of equipment used, size of area being treated, and range site. Specialized equipment is not available for pitting or chisel plowing clubmoss, and standard farm machinery is usually modified or used as it. In Montana, pitting was accomplished using a modified one-way disk. A heavy breaking disk was substituted in the analysis at a cost of \$ 32.00/ha (Saskatchewan Agriculture and Food 1997), and hereafter is referred to as disking. A heavy duty cultivator can be utilized for chisel plowing. Cost of a heavy duty cultivator is \$ 9.70/ha for grain (Saskatchewan Agriculture and Food 1996). However, since the treatment needs to be applied 3 times, cost of the first cultivation was \$28.00/ha, decreasing to \$9.70 (costs for grain production) for each of the second and third cultivation treatments. Total cost of the heavy duty cultivator for the chisel plowing treatment is thus \$47.40/ha.

Grazing deferment

Grazing was not allowed the first 2 years after disking or chisel plowing to allow plants on the site to recover or new plants to establish. Costs of grazing deferment (Table 4) was calculated as:

Value per animal = Revenue - total operation costs
= gain/animal/day X Grazing period (days)/year X \$/kg - total operation cost
= 0.794 kg/day X 110 days X \$2.25/kg- total operation cost

Cost of grazing deferment = untreated forage yield X 55% / 345 kg/AUM/3.5months X \$/animal

Cost of deferring grazing was greater on loamy than sandy range sites, and greatest in the Dark Brown Soil Zone.

Table 4. Cost of deferring grazing for 2 years on loamy and sandy range sites in 3 soil zones after disking or chisel plowing rangeland in Saskatchewan.

	Soil zone					
Treatment	Dry Brown		Moist Brown		Dark Brown	
	Range site					
	Loamy	Sandy	Loamy	Sandy	Loamy	Sandy
	Costs of grazing deferment (\$ ha^{-1})					
Disking	14.06	11.30	25.37	19.26	30.63	22.68
Chisel plowing	13.87	10.94	25.53	19.15	30.61	22.82

Operation costs

Operation costs start in the third year after disking or chisel plowing. In this analysis, costs of purchasing and selling feeder animals, veterinary medicine and supplies, fuel and repair, insurance on investment, office supplies, and death loss were included. Some costs were not included in this analysis. Feeder cost was excluded because the weight change between before and after grazing was considered. Water facilities were assumed to be sufficient for raising additional animals in each area. Fencing did not change after treatment. Taxes for pasture improvement were not included because the tax rate in Saskatchewan is determined in terms of area, based on 3 factors: climate, range site, and topography. None of these factors were affected by mechanical treatments. Operation costs for different soil zones and range sites are presented in Tables 5 and 6.

Costs of feeder purchasing consists of buying commission and trucking. A buying commission is \$6.00/animal was assumed (Saskatchewan Agriculture and Food 1997), but trucking costs vary with the number of animals. Trucking costs were calculated as:

\$150.00/load X number of loads (80 animals/load), additional number of feeders 1000 ha^{-1}). Cost per animal was converted into cost ha^{-1}.

Selling costs included selling commission, selling cost, and trucking. Selling commission and selling cost were \$15/animal and \$ 3.05/animal, respectively. Cost of trucking for sale was calculated the same as with purchasing, except that it costs \$55 animal/load, and 1.5% death loss was considered. All other operational costs were calculated based on the cost/animal (Saskatchewan Agriculture and Food 1997) times the additional number of animals/ha.

Costs and benefits must be compared on a common time base, which is present value. A common time base is used because a money spent today is not equal to money spent one year ago. Money received now is not same as a money received 5 years later. To equalize the value of money, a discount rate must be considered. Today's money can be invested for a year, whereas next year's money must be discounted. Tables 7 and 8 show the investment time pathway in accumulated present value at 5, 10, 15, 20, 25, and 30-year intervals for the 2 mechanical treatments. Within soil zones, cost is generally greater on loamy range sites than on sandy range sites. Costs are least in the Dry Brown Soil Zone and greatest in the Dark Brown Soil Zone.

Benefits

Benefits in this study were predicted by the increment in animal units resulting from the increased grazing capacity. Calculation of benefits therefore should be additional animals raised per unit area after improvement multiplied by animal value per animal minus 1.5% death loss. An example for the loamy range site in the Dry Brown Soil Zone is: 0.067 AUM/ha X $ 196.50/AUM X 98.5%=$12.97/ha/year. Generally expected economic benefits are greater on loamy than sandy range sites, and within range sites benefits increased from Dry Brown to Dark Brown Soil Zones (Table 9).

Table 5. Operational cost of disking on loamy and sandy range sites in 3 soil zones in Saskatchewan.

	Soil zone					
Item	Dry Brown		Moist Brown		Dark Brown	
	Range site					
	Loamy	Sandy	Loamy	Sandy	Loamy	Sandy
	Operational cost ($ ha^{-1})					
Feeder purchase	0.56	0.48	0.71	0.63	1.04	0.95
Veterinary	0.96	0.78	1.32	1.15	1.76	1.57
Fuel and repair	0.13	0.11	0.18	0.16	0.24	0.22
Insurance	0.05	0.04	0.07	0.06	0.09	0.08
Office supplies	0.02	0.01	0.03	0.02	0.034	0.03
Death loss	0.77	0.62	1.06	0.92	1.41	1.26
Labor	0.60	0.49	0.81	0.72	1.10	0.98
Feeder selling	1.37	1.13	1.97	1.76	2.51	2.28
Total cost	4.47	3.65	6.17	5.42	8.19	7.38

Table 6. Operational cost of chisel plowing on loamy and sandy range sites in 3 soil zones in Saskatchewan.

	Soil zone					
Item	Dry Brown		Moist Brown		Dark Brown	
	Range site					
	Loamy	Sandy	Loamy	Sandy	Loamy	Sandy
	Operational cost ($ ha^{-1})					
Feeder purchase	0.39	0.42	0.48	0.45	0.58	0.54
Veterinary	0.56	0.46	0.78	0.71	1.02	0.92
Fuel and repair	0.08	0.06	0.11	0.10	0.14	0.13
Insurance	0.03	0.02	0.04	0.04	0.05	0.05
Office supplies	0.01	0.01	0.02	0.01	0.02	0.02
Death loss	0.45	0.37	0.62	0.57	0.82	0.74
Labor	0.35	0.29	0.49	0.44	0.64	0.58
Feeder selling	0.80	0.89	1.13	1.05	1.44	1.31
Total cost	2.66	2.53	3.66	3.36	4.71	4.28

Table 7. Present value of costs of disking and chisel plowing on loamy and sandy range sites in 3 soil zones in Saskatchewan at 8% discount over a 5 to 30 year period after treatment.

		Soil zone					
Treatment	Years	Dry Brown		Moist Brown		Dark Brown	
		Range site					
		Loamy	Sandy	Loamy	Sandy	Loamy	Sandy
		Present value of treatment costs ($ ha^{-1})					
Disking	5	65.02	57.88	77.61	71.16	92.97	86.37
	10	77.69	67.82	94.37	85.91	115.22	106.42
	15	86.32	74.58	105.78	95.94	130.36	120.67
	20	92.20	79.18	113.56	102.78	140.67	129.35
	25	96.19	82.32	118.84	107.43	147.68	135.67
	30	98.91	884.45	122.43	110.59	152.46	139.98
Chisel plowing	5	74.52	69.00	86.13	80.67	99.82	94.05
	10	81.76	75.87	96.07	88.80	112.63	105.68
	15	86.69	80.56	102.83	96.02	121.34	113.60
	20	90.05	83.74	107.44	100.25	127.27	118.99
	25	92.33	85.91	110.57	103.03	131.31	122.66
	30	93.88	87.38	112.71	105.09	134.06	125.16

Table 8. Present value of costs of disking or chisel plowing on loamy and sandy range sites in 3 soil zones in Saskatchewan at 10% discount over a 5 to 30 year period after treatment.

		Soil zone					
Treatment	Years	Dry Brown		Moist Brown		Dark Brown	
		Range site					
		Loamy	Sandy	Loamy	Sandy	Loamy	Sandy
		Present value of treatment costs ($ ha^{-1})					
Disking	5	63.01	56.23	75.20	68.99	89.96	83.61
	10	74.07	64.84	89.72	81.77	109.23	100.98
	15	80.67	70.19	98.74	89.70	121.2	111.76
	20	85.12	73.51	104.34	94.63	128.63	118.46
	25	87.75	75.57	107.81	97.68	133.24	122.12
	30	89.38	76.85	109.97	99.58	136.10	125.20
Chisel plowing	5	72.65	67.29	83.85	78.57	97.08	91.50
	10	78.92	73.24	92.46	86.48	108.17	101.58
	15	82.81	76.94	97.81	91.39	115.06	107.84
	20	95.23	79.24	101.13	94.44	119.34	111.72
	25	86.74	80.67	103.19	96.34	121.99	114.14
	30	87.67	81.55	104.47	97.51	123.64	115.63

Table 9. Economic benefits of disking or chisel plowing on loamy and sandy range sites in 3 soil zones in Saskatchewan.

Treatment	Soil zone: Dry Brown		Moist Brown		Dark Brown	
	Range site: Loamy	Sandy	Loamy	Sandy	Loamy	Sandy
	Economic benefits of treatment ($ ha^{-1})					
Disking	12.97	10.45	17.81	15.48	23.61	21.09
Chisel plowing	7.55	6.19	10.45	9.48	13.74	12.38

Time pathway of accumulated benefits

Present value of income on loamy range sites in the Dark Brown Soil Zone is highest, and that for sandy range sites in dry areas in Brown Soil Zone is lowest (Tables 10 and 11). Present value of chisel plowing is lower than disking.

Results

Generally, disking or chisel plowing range in the Dark Brown Soil Zone had the highest net present value, and lowest returns are predicted in the Dry Brown Soil Zone. All net present values for chisel plowing were negative, indicating this treatment is not economically feasible on any range site in all soil zones at either 8% or 10% interest rate over a 5 to 30 year period (Table 12). At 8% discount rate, disking is economically feasible for within 10 years on all range sites and soil zones, except on sandy range sites in the Brown Soil Zone, where over 15 years were needed to recover costs. At a 10% discount rate, benefits of disking could cover the total cost in a 15-year period except on sandy range sites in the Dry Brown Soil Zone.

Internal rate of return overcomes the disadvantage of net present value, which forces selection of interest rates or discount rates. Internal rate of return compares with market interest rates directly to determine economic feasibility (Table 13). Disking or chisel plowing is not economically feasible unless the internal rate of return of the specific treatment on the corresponding range site is greater than market interest rate. Internal rates of return are greater for disking than chisel plowing, and rates are greater in the Dark Brown than the Dry Brown Soil Zone.

Break-even analysis indicates the time required to recover costs of treatment for disking or chisel plowing vary with range site, soil zone, and interest rate (Table 14). Fewer years are needed to recover costs of disking than chisel plowing on the same range site in the same soil zone; more time is needed to recover costs with higher discount rates. More than 30 years are required to recover costs of chisel plowing regardless of soil zone, range site, and discount rate.

Conclusions

Under best case scenarios, disking and chisel plowing can increase forage yields and stocking rates on fair condition range to levels similar to excellent condition. However, weather is more important in determining forage productivity than mechanical disturbance (Haferkamp *et al.* 1993). Based on results of studies in Montana (Ryerson *et al.* 1968, 1974), chisel plowing improves yield less than disking. The economic feasibility of disking or chisel plowing rangeland depends upon treatment used, costs of treatment, forage production before treatment, increment of forage production after treatment, value of increased forage production, effective life of the treatment, interest rate, and grazing deferment. Costs and benefits from mechanical disturbance on range depend upon the additional animal units produced, return to grazing per animal unit, and carrying capacity. Additional grazing can be expected following mechanical disturbance on loamy or sandy range sites in the 3 soil zones tested. Economic feasibility of mechanical disturbance of loamy range sites is greater than sandy range sites, and expected rates of return are higher in Dark Brown Soil Zone than in the Dry or Moist Brown Soil Zone.

Mechanical disturbance methods are characterized by high initial costs and low rates of return. Furthermore, costs and benefits must be compared to complete economic analysis, depending on which discount rate used. Of the 2 treatments evaluated, economic feasibility appears greater for disking than chisel plowing. Recovery of total costs of disking ranged from a low of 10 to 11 years on loamy range sites in the Dark Brown Soil Zone to 17 to 24 years on sandy range sites in the Brown Soil Zone depending on discount rate. Recovery of costs associated with chisel plowing would take over 30 years at 8% or 10% discount rate, regardless of range sites and soil zone. It must be stressed that these values assumed a constant level of increased herbage yield over the duration of the project. However, the validity of this assumption must be questioned for published data suggest that herbage production may diminish in 1 to 6 years (Houston 1957, Lorenz and Rogler 1962, Ryerson *et al.* 1968, Wight and White 1974, Rauzi 1974, 1975, White *et al.* 1981, Hart *et al.* 1985, White 1985) in which case mechanical disturbance is not economically feasible.

Cost-benefits analysis suggests that decision makers must understand completely each situation before deciding whether to proceed with mechanical disturbance of rangeland. The decision must be based on the equipment used, whether equipment is being rented or owned, the length of time grazing is deferred, size and location of the area treated, range condition, range site, time of year treated, life of the project, interest rate, market price, and expected returns from mechanical disturbance. Comparison of net present value of costs and benefits or internal rate of return will show if the proposed mechanical disturbance of range is economically desirable in a certain period of time.

Because of the lack of production data following disturbance of rangeland in Saskatchewan, this study was carried out using yield data from Montana to estimate the yield increases. Relationships developed for other rangelands could lead to over or under-estimate the yield increases in Saskatchewan. Estimated forage yield in Saskatchewan was based on a simplistic assumption that the yield ratio of each mechanical treatment was constant across range sites and soil zones. This assumption could also bias estimates of yield.

The scope of the evaluation adopted in this analysis only considered direct market value and excluded indirect values such as environmental value or recreational value, option value, existence value, or bequest value for mechanical improvements, which would further imply that the total value and economic worth of the treatments are higher than the estimated value. Price of livestock and other productive inventory were constant and ignored inflation. Furthermore, the life of the mechanical disturbance was difficult to determine because no such treatments have been studied in Saskatchewan. It is questionable whether beneficial treatment effects on herbage production exceed 10 years.

In summary this economic analysis will prove useful in prioritizing range management practices. Range managers considering disking or chisel plowing to reduce clubmoss and improve forage productivity will find the net present value of mechanical disturbance (Table 12), internal rate of return (Table 13), and the number of years to break even (Table 14) useful in making economically prudent decisions.

Table 10. Present value of disking or chisel plowing on loamy and sandy range sites in 3 soil zones in Saskatchewan at 8% discount over a 5 to 30 year period after treatment.

		Soil zone					
Treatment	Years	Dry Brown		Moist Brown		Dark Brown	
		Range site					
		Loamy	Sandy	Loamy	Sandy	Loamy	Sandy
		Present value of treatment benefits (\$ ha^{-1})					
Disking	5	28.65	23.09	39.34	34.21	52.17	46.57
	10	63.89	51.50	87.73	76.29	116.34	103.58
	15	87.87	70.82	120.66	104.92	160.01	142.84
	20	104.20	83.98	143.08	124.41	189.73	169.37
	25	115.31	92.93	158.33	137.68	209.96	187.42
	30	122.87	99.03	168.71	146.70	223.72	199.71
Chisel plowing	5	16.68	13.68	23.09	20.95	30.36	27.37
	10	37.19	30.52	51.50	46.73	67.70	61.03
	15	51.15	41.97	70.82	64.27	93.12	83.94
	20	60.66	49.77	83.98	76.20	110.42	99.53
	25	67.12	55.07	92.93	84.33	122.19	110.14
	30	71.52	58.69	99.03	89.96	130.20	117.36

Table 11. Present value of benefits of disking or chisel plowing on loamy and sandy range sites in 3 soil zones in Saskatchewan at 10% discount over a 5 to 30 year period after treatment.

		Soil zone					
Treatment	Years	Dry Brown		Moist Brown		Dark Brown	
		Range site					
		Loamy	Sandy	Loamy	Sandy	Loamy	Sandy
		Present value of treatment benefits (\$ ha^{-1})					
Disking	5	26.65	21.48	36.60	31.82	48.53	43.32
	10	57.18	46.08	78.51	68.27	104.11	92.94
	15	70.13	61.36	104.54	90.90	138.62	123.75
	20	87.90	70.84	120.70	104.95	160.05	142.87
	25	95.20	76.73	130.73	113.68	173.35	154.75
	30	99.74	80.39	136.96	119.09	181.62	162.13
Chisel plowing	5	15.52	12.73	21.48	19.49	28.24	25.45
	10	33.28	27.31	46.08	41.85	60.59	54.61
	15	44.32	36.36	61.36	55.68	80.67	72.72
	20	51.17	41.98	70.84	64.28	93.14	83.96
	25	55.42	45.47	76.73	69.63	100.89	90.94
	30	58.06	47.64	80.39	72.95	105.69	95.27

Table 12. Net present value of disking or chisel plowing on loamy and sandy range sites in 3 soil zones in Saskatchewan over a 5 to 30 year period after treatment.

Treatment	Discount Rate (%)	Year	Soil zone					
			Dry Brown		Moist Brown		Dark Brown	
			Range site					
			Loamy	Sandy	Loamy	Sandy	Loamy	Sandy
			Net present value of mechanical treatments ($\$ha^{-1}$)					
Disking	8	5	-36.36	-34.78	-38.26	-36.85	-40.80	-39.80
		10	-13.80	-16.32	-6.64	-9.62	-6.03	-2.57
		15	1.55	-3.76	14.87	8.98	29.64	22.77
		20	12.00	4.80	29.53	21.63	49.06	40.01
		25	19.11	10.62	39.50	30.25	62.28	51.75
		30	23.95	14.58	46.28	36.11	71.27	59.74
	10	5	-36.43	-34.75	-38.60	-37.17	-41.43	-40.29
		10	-16.89	-18.76	-11.21	-13.50	-6.21	-8.04
		15	-4.71	-8.83	5.80	-1.20	17.42	11.98
		20	2.77	-2.66	16.36	10.32	31.42	24.41
		25	7.53	1.16	22.92	15.99	40.11	32.13
		30	10.36	3.54	26.99	19.51	46.61	36.93
Chisel plowing	8	5	-57.84	-55.31	-63.04	-59.72	-69.46	-66.69
		10	-44.57	-45.38	-44.57	-43.08	-44.92	-44.65
		15	-35.54	-38.58	-32.01	-31.76	-28.22	-29.67
		20	-29.39	-33.97	-23.46	-24.05	-16.86	-19.46
		25	-25.21	-30.84	-17.64	-18.81	-9.12	-12.52
		30	-22.36	-28.70	-13.68	-15.24	-3.86	-7.795
	10	5	-57.14	-54.56	-62.37	-59.07	-68.84	-66.04
		10	-45.64	-45.93	-46.38	-44.66	-47.58	-46.96
		15	-38.50	-40.58	-36.45	-35.72	-34.39	-35.12
		20	-34.07	-37.26	-30.29	-30.16	-26.19	-27.76
		25	-31.32	-35.19	-26.46	-26.71	-21.10	-23.20
		30	-29.61	-33.99	-24.08	-24.57	-17.94	-20.36

Table 13. Internal rate of return for disking or chisel plowing on loamy and sandy range sites in 3 soil zones in Saskatchewan over a 5 to 30 year period after treatment.

		Soil zone					
Treatment	Years	Dry Brown		Moist Brown		Dark Brown	
		Range site					
		Loamy	Sandy	Loamy	Sandy	Loamy	Sandy
		Internal rate of return for treatments (%)					
Disking	5	---[1]	---	---	---	---	---
	10	2	0	6	4	8	7
	15	8	7	12	10	14	13
	20	11	9	13	12	16	15
	25	12	10	14	13	16	15
	30	12	11	14	13	16	16
Chisel plowing	5	---	---	---	---	---	---
	10	---	---	---	---	---	---
	15	---	---	0	0	2	2
	20	2	0	4	3	5	5
	25	3	2	5	5	7	6
	30	4	3	6	5	7	7

[1] --- Internal rate of return is negative.

Table 14. Predicted number of years required to break even or recapture costs of disking or chisel plowing on loamy and sandy range sites in 3 soil zones in Saskatchewan.

		Soil zone					
Treatment	Discount Rate (%)	Dry Brown		Moist Brown		Dark Brown	
		Range site					
		Loamy	Sandy	Loamy	Sandy	Loamy	Sandy
		Time required to recapture cost of treatments (Years)					
Disking	8	15	17	12	13	10	11
	10	18	24	14	15	11	12
Chisel plowing	8	>30	>30	>30	>30	>30	>30
	10	>30	>30	>30	>30	>30	>30

Executive Summary

Clubmoss forms a ground cover on rangeland in the Brown and Dark Brown Soil Zones of southern Saskatchewan and Alberta. Many producers believe clubmoss inhibits growth and productivity of desirable plants by intercepting rainfall and competing for soil water. Mechanical disturbances have often been applied to rangeland to increase water capture (Branson *et al.* 1966, Wight *et al.* 1978). In some situations, however, decreased plant cover following mechanical disturbance reduced loss of soil water through evapotranspiration. In other situations, nitrogen liberated through mechanical disturbance and subsequent increase in evapotranspiration from growing plants reduced soil water more on disturbed sites than on undisturbed sites. Similarly, adding nitrogen fertilizer may increase growth of plants and soil water extraction (Wight *et al.* 1978). Greater production following mechanical disturbance of range has also been observed (Dolan 1966, Wagner 1966, Taylor 1967). This increased production was attributed to a combination of factors including removal of clubmoss, competition for water, and increased availability of soil nitrogen resulting from the decomposition of organic materials. The influence of individual factors had not, however, been isolated until this research was completed.

The objectives of the studies reported herein were to:

- Determine if clubmoss intensifies drought and subsequently reduces forage productivity in Northern Mixed Prairie;
- Determine clubmoss and precipitation affects on seedling emergence and survival;
- Determine relationships between clubmoss cover, range condition, and seed reserves in the soil seedbank, and;
- Complete an economic analysis of costs and benefits of mechanical treatment of rangeland to alter cover of clubmoss.

The salient findings of these studies indicate:

- Soil water and leaf xylem water potentials generally declined through the summer and usually did not respond to sward disturbances including mechanical disturbance (cultivation), adding nitrogen, killing clubmoss, removing clubmoss, and an undisturbed control. Precipitation had a more consistent effect on soil and leaf xylem water potentials of Junegrass and blue grama than did sward disturbances. Irrigating did not usually affect leaf xylem water potentials of Junegrass (*Koeleria cristata* (L.) Pers.) and blue grama (***Bouteloua gracilis*** (H.B.K.) Lag) relative to control, but reducing precipitation decreased leaf xylem water potentials compared to control and irrigation, respectively. Therefore, the hypothesis that clubmoss reduces soil water and increase plant water stress is rejected. Alternatively it is proposed that amounts of precipitation have greater impacts on soil water and plant water status than clubmoss.
- Graminoids responses to sward disturbances were inconsistent, but their production increased when irrigated relative to reducing precipitation. Response of biomass production to sward disturbances and precipitation treatments was also variable or no differences were observed. Therefore the hypothesis that clubmoss reduces productivity is rejected. The

alternative hypothesis that the amount of precipitation has greater effects on soil water and plant water status than clubmoss is proposed.

- When 0 to 25 mm of water was added as simulated precipitation events, clubmoss generally had no effect on soil water and leaf xylem water potentials of Junegrass and blue grama up to 7 days after the precipitation event. Therefore the hypothesis that clubmoss reduces the effectiveness of precipitation is rejected.
- Emergence of native seedlings is strongly limited by precipitation because in all cases emergence of seedlings was greatest when irrigated. In two of three years, survival of seedlings was also limited by precipitation while in one year survival was unaffected by precipitation or seedbed conditions.
- Emergence and survival of seedlings in different plant groups (grasses vs. forbs), seedbed characteristics, and year, preclude any general statements about beneficial, neutral, or negative effects of clubmoss on emergence and survival of native grasses and forbs. Site conditions, timing, frequency and intensity of precipitation, and other environmental factors likely interact to illicit unique seedling emergence and survival. Because no consistent effects of clubmoss on seedling emergence and survival were observed, the hypothesis that clubmoss has negative effects on seedling dynamics is rejected.
- Provided seeds are present in the soil seedbank, management activities that improve the water balance on a site appear more important in promoting seedling emergence and survival of perennial grasses and forbs than activities that are designed to reduce cover of clubmoss.
- Relationships between clubmoss cover and range condition score and the number of seeds and species composition of the soil seedbank were evaluated on 100 pastures in Mixed Prairie in the Brown Soil Zone of southern Saskatchewan. Of the 100 pastures sampled, 71 were classed as Loamy range sites, 19 were Thin range sites, and 10 were Sands-Sandy range sites. On average 27% of the pastures were in poor condition, 69% were in fair condition, and 4% were in good condition.
- Seedling densities emerging from soil samples tended to increase as range condition decreased, and ranged from 0 to nearly 5,300 seeds m^{-2}. Seedlings of increaser species were most common, followed by invader species; decreaser species were uncommon in the seedbank. *Koeleria cristata* and *Carex* sp. were most important among graminoids in the seedbank. *Androsace septentrionalis* and *Artemisia frigida* were the most important annual and perennial forbs, respectively.
- Seed densities were generally not related to clubmoss cover and range condition score. The lack of relationships between clubmoss cover and seed densities suggests that other factors such as climatic conditions and lack of seed production probably place greater control on seed reserves in the soil, and potential recruitment of new plants. The hypothesis that clubmoss reduces seedling establishment is rejected, and the alternative hypothesis that seedling establishment is controlled by amounts and kinds of seeds in the seedbank.
- When sites are disturbed to control clubmoss, a plant community dominated by early successional species (increasers and invaders) should be anticipated to develop from the

seedbank. Under rare circumstances, substantial amounts of decreaser species may be present in the seedbank and they may colonize the site following mechanical disturbance.

- Cost and benefit analysis of disking or chisel plowing were determined for sandy and loamy range sites in the Dry and Moist Brown Soil Zones, and the Dark Brown Soil Zone in Saskatchewan by valuation of forage in terms of increased livestock production after treatment. Under best case scenarios, disking and chisel plowing increases forage yields and stocking rates on fair condition rangeland to levels similar to that in excellent condition.
- Economic feasibility of disking or chisel plowing depends upon treatment used, cost of treatment, forage production before treatment, increment of forage production after treatment, value of increased forage production, effective life of treatment, interest rate, and grazing deferment. All net present values for chisel plowing were negative, indicating this treatment is not economically feasible on any range site in all soil zones at either 8% or 10% interest rate.
- More than 30 years are required to recover costs of chisel plowing regardless of soil zone, range site, and discount rate. Economic feasibility of disking is greater than chisel plowing. Recovery of total costs of disking on a loamy range site occurred at 10 and 11 years post-treatment in the Dark Brown Soil Zone, 12 and 14 years in the Moist Brown Soil Zone, and 15 and 18 years in the Dry Brown Soil Zone at discount rates of 8 and 10%, respectively. At 8 and 10% discount rates respectively, 11 and 12 years are needed to recover costs of disking on sandy range sites in the Dark Brown Soil Zone, 13 and 15 years in the Moist Brown Soil Zone, and 17 and 24 years in the Dry Brown Soil Zone.
- It is questionable whether beneficial effects of disking or chisel plowing on herbage production exceed 10 years. Therefore disking or chiseling do not appear economical. Range managers considering disking or chisel plowing to reduce clubmoss on rangeland and improve forage productivity will find the net present value, internal rate of return, and the predicted number of years to break even useful in making economically prudent decisions.

Removing clubmoss from the sward did not increase or decrease soil water, reduce or improve plant water stress, improve productivity, and improve seedling emergence and establishment. Limited seed reserves in the soil likely place greater controls on emergence of seedling of desired plants than clubmoss. Therefore decisions to alter cover of clubmoss on rangelands must be based on criteria other than the hydrologic cycle, productivity, and plant reproduction. Economic considerations may thus be the determining factor of whether to attempt alter clubmoss cover. However, economic analyses indicate that chisel plowing is not economically feasible on any range site in the Brown and Dark Brown soil zones, and cost recovery of disking from 10 and 24 years. Information is presented that will allow range managers to make economically prudent decisions.

As a general rule environmental conditions, specifically the amount and timing of precipitation, likely outweigh any impacts that clubmoss may have on soil water, plant water stress, seedling emergence, and seedling survival. Therefore managers may want to maximize the functioning of the hydrologic cycle, the ability of plants to access water, and ensure that desired species are allowed to produce seed for regeneration. When these finding are considered together, it is concluded that range managers may find it useful focus their management efforts on issues other than clubmoss.

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Personnel, Person Years, and Salary Expenditures from Project.

Person	Cumulative person years	Salary (%)
J.T. Romo	3.1	000
Tyler Colberg	2.17	100
David Junor	2.17	100
Peng Hongjia	1.67	000
Vicki Jay	0.17	100
Tracy Chanig	0.05	100
Colleen Cockburn	0.33	100
Garth Wruck	0.33	100
Judy Haraldson	0.10	100
Total	10.09	----

Equipment

No equipment was purchased.

Project Developed Materials

No materials have been developed from the project to date.

Publications in various stages of preparation that will arise from this research include the following:

Colberg, T. 1999. The impact of clubmoss (*Selaginella densa* Rydb.) on water relations, productivity, and plant community characteristics in Northern Mixed Prairie. M.Sc. Thesis. University of Saskatchewan, Saskatoon, SK. 129 pp.

Colberg, T., and J.T. Romo. 2000. Clubmoss effects on plant water status in Northern Mixed Prairie. Journal of Range Management.

Hongia, P, J.T. Romo, S.N. Kulshrestha, and R.E. Redmann. 2000. Economics of clubmoss control on Saskatchewan Rangelands: A Fact Sheet.

Hongia, P, J.T. Romo, S.N. Kulshrestha, and R.E. Redmann. 2000. Economic analysis of mechanically disturbing rangeland to reduce clubmoss in Saskatchewan. Journal of Range Management.

Romo, J.T. 2000. Clubmoss and soil-seedbank relationships in Northern Mixed Prairie. Journal of Range Management.

Romo, J.T. and D. Junor. 2000. Clubmoss effects on emergence and survival of grass and forb seedlings in Northern Mixed Prairie. Journal of Range Management.

Romo, J.T. and D. Junor. 2000. Microsites for establishment of crested wheatgrass in Northern Mixed Prairie. Natural Areas Journal.

Project Photos

None presented.

SADF Acknowledgment

SADF will be acknowledged whenever results of this project are presented or published.

Expense Statement

A final statement of expenses will be submitted by the Research Services and Accounting, University of Saskatchewan.

Appendix A

Appendix A, Table 1. Canopy cover of plants in 4 months for 3 precipitation treatments and 5 sward disturbances at Dundurn in 1997.

Precipitation treatment	Cover component	May						Jun					
		Sward disturbance											
		Control	Nitrogen irrigation	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Control	Nitrogen irrigation	Clubmoss killed	Mechanical	Clubmoss removed	Mean
		Canopy cover (%)											
Control	Total	45	36	37	34	20	28	31	45	40	45	21	27
Reduced		44	43	39	24	17	29	30	35	48	29	26	31
Irrigation		46	46	30	34	23	24	31	50	41	35	24	56
Mean		41	41	35	31	20		12	43	43	36	24	
SE^1		27	3					80	5				
Control	Total forbs	15	15	19	13	8	10	13	24	19	27	9	6
Reduced		14	14	12	12	8	11	11	20	30	14	11	11
Irrigation		14	14	12	19	8	9	12	23	29	17	9	27
Mean		14	14	14	15	8		12	22	26	19	10	
SE^1		6	2					40	4				
Control	clubmoss	56	56	50	50	14	6	35	44	32	50	12	3
Reduced		50	50	62	56	14	14	39	44	38	50	18	6
Irrigation		50	50	68	61	29	6	43	39	44	50	24	3
Mean		52	52	60	56	19		39	42	38	50	18	
SE^1		35	4					15	2				
Control	Total graminoids	21	21	18	21	12	18	18	21	21	18	12	21
Reduced		29	29	27	12	9	18	19	15	18	15	15	20
Irrigation		32	32	18	15	15	15	19	27	12	18	15	29
Mean		27	27	21	16	12		19	21	17	17	14	
SE^1		23	3					24	3				
Control	Junegrass	15	15	12	15	6	12	12	6	6	3	6	6
Reduced		23	23	21	6	3	12	13	3	6	6	6	6
Irrigation		26	26	12	9	9	9	13	3	3	9	6	3
Mean		21	21	15	10	6		13	4	5	6	6	
SE^1		21	3					4	1				
Control	blue grama	3	3	3	3	3	3	3	9	12	6	3	12
Reduced		3	3	3	3	3	3	3	6	6	3	6	11
Irrigation		3	3	3	3	3	3	3	21	6	3	6	23
Mean		3	3	3	3	3		3	12	8	4	5	
SE^1		-	-					20	3				
Control	needle- and end-thread	3	3	3	3	3	3	3	6	3	9	3	3
Reduced		3	3	3	3	3	3	3	6	6	6	3	3
Irrigation		3	3	3	3	3	3	3	3	3	6	3	3
Mean		3	3	3	3	3		3	5	4	7	3	
SE^1		-	-					2	1				
Control	bare ground	3	3	3	3	53	59	24	3	3	3	56	62
Reduced		11	11	3	3	47	59	24	3	3	3	56	56
Irrigation		3	3	3	3	38	53	20	3	6	3	53	38
Mean		5	5	3	3	46		23	3	4	3	55	
SE^1		13	2					30	3				
Control	litter	12	12	9	9	3	6	8	6	12	9	3	6
Reduced		9	9	6	9	6	6	7	18	9	6	3	9
Irrigation		12	12	6	6	6	14	9	6	6	9	3	3
Mean		11	11	7	8	5		8	10	9	8	3	
SE^1		8	2					12	2				

Precipitation treatment	Cover component	Jul						Aug					
		Sward disturbance											
		Control	Nitrogen irrigation	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Control	Nitrogen irrigation	Clubmoss killed	Mechanical	Clubmoss removed killed	Mean
		Canopy cover (%)											
Control	Total	34	39	52	45	20	39	37	34	38	37	18	27
Reduced		32	29	26	44	20	24	28	29	24	24	27	29
Irrigation		40	46	51	44	49	44	46	32	30	38	40	37
Mean		18	38	43	45	30		17	32	31	32	28	
SE^1		15	51					39	4				
Control	Total forbs	17	18	28	13	8	24	18	16	14	14	6	7
Reduced		17	11	14	23	8	9	13	9	12	9	12	11
Irrigation		21	13	21	23	28	20	21	9	12	26	19	14
Mean		18	14	21	20	15		17	11	13	16	12	
SE^1		44	4					23	3				
Control	clubmoss	28	38	26	38	6	6	23	50	50	62	9	3
Reduced		31	44	56	50	3	6	32	44	62	74	6	3
Irrigation		32	29	21	38	9	3	20	44	44	44	18	3
Mean		30	37	34	42	6		25	46	52	60	11	
SE^1		66	5					67	5				
Control	Total graminoids	17	21	24	32	12	15	19	18	24	23	12	20
Reduced		15	18	12	21	12	15	15	20	12	15	15	18
Irrigation		19	33	30	21	21	24	25	23	18	12	21	23
Mean		17	24	22	25	15		20	21	18	16	16	
SE^1		30	3					28	3				
Control	Junegrass	5	6	6	3	6	3	4	6	3	3	6	3
Reduced		5	6	6	6	6	3	5	3	3	3	3	3
Irrigation		4	9	12	6	9	9	9	3	6	3	6	6
Mean		5	7	8	5	7		5	4	4	3	5	
SE^1		2	1					2	1				
Control	blue grama	8	9	12	20	3	9	10	9	18	11	3	14
Reduced		6	9	3	6	3	9	6	14	6	6	3	12
Irrigation		12	18	9	12	9	9	11	14	6	3	12	14
Mean		9	12	8	13	5		9	13	10	6	6	
SE^1		15	2					22	3				
Control	needle- and end-thread	4	6	6	9	3	3	5	3	3	9	3	3
Reduced		4	3	3	9	3	3	4	3	3	6	9	3
Irrigation		3	6	9	3	3	6	5	6	6	6	3	3
Mean		4	5	6	7	3		5	4	4	7	5	
SE^1		6	1					5	1				
Control	bare ground	25	3	3	3	51	38	19	6	3	3	74	38
Reduced		24	3	3	3	71	48	25	3	3	3	74	62
Irrigation		20	6	3	3	38	50	20	3	3	3	26	44
Mean		23	4	3	3	53		21	4	3	3	58	
SE^1		58	5					153	8				
Control	litter	7	3	3	3	3	3	3	3	6	3	6	3
Reduced		9	26	9	9	3	6	10	6	3	12	3	6
Irrigation		5	3	3	3	3	3	3	6	6	3	3	3
Mean		7	10	5	5	3		5	5	5	6	4	
SE^1		25	3					8	2				

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^{1} Within cover components the first value is standard error for sward disturbance and the second value is standard error for precipitation treatment.

Appendix A, Table 2. Canopy cover of plants in 4 months for 3 precipitation treatments and 5 sward disturbances at Rudy in 1998.

Precipitation treatment	Cover component	May						Jun.						Jul.					
		Sward treatment																	
		Control	Nitrogen added	Clubmoss killed	Mech-anical	Clubmoss removed	Mean	Control	Nitrogen added irrigation	Clubmoss killed	Mech-anical	Clubmoss removed	Mean	Control	Nitrogen added	Clubmoss killed	Mech-anical	Clubmoss removed	Mean
		Canopy cover(%)																	
Control	Total	32	42	20	29	37	31	28	30	18	21	32	26	38	49	36	28	33	37
Reduced		28	28	27	13	19	23	24	27	18	25	18	22	28	24	26	27	18	24
Irrigation		32	30	26	23	25	27	27	36	38	26	28	31	29	28	54	38	41	37
Mean		31	33	25	22	27		26	30	24	24	26		32	34	38	31	31	
SE[1]		38	4					29	3					61	5				
Control	Total forbs	8	6	0	5	19	8	4	4	0	0	8	3	11	8	13	4	4	8
Reduced		4	4	9	1	1	4	0	0	0	4	0	1	4	0	8	0	0	2
Irrigation		8	9	8	5	4	7	0	15	0	0	4	4	8	4	4	11	11	8
Mean		7	6	6	4	8		1	6	0	1	4		8	4	8	5	5	6
SE[1]		26	3					16	3					15	2				
Control	clubmoss	23	32	36	9	3	24	26	26	50	12	3	23	12	12	21	6	3	11
Reduced		26	26	32	6	3	19	44	24	38	9	3	24	9	12	12	3	3	8
Irrigation		23	26	29	6	3	17	32	21	20	6	9	17	18	21	9	6	3	11
Mean		24	28	39	7	3		34	24	36	9	5		13	15	14	5	3	
SE[1]		35	4					63	5					15	2				
Control	Total graminoids	36	20	24	18	23	24	26	18	21	24	23	27	41	23	24	29	29	
Reduced		24	24	18	12	18	19	24	27	18	21	18	21	24	24	18	27	18	22
Irrigation		24	21	18	18	21	20	27	21	38	26	24	27	21	24	50	27	30	29
Mean		24	27	19	18	19		25	24	24	23	22		24	30	30	26	26	7
SE[1]		54	5					39	4					106	6				
Control	Junegrass	6	21	3	3	6	7	12	9	3	6	9	8	6	9	3	9	9	7
Reduced		9	6	3	6	6	6	12	9	3	6	6	7	6	6	3	6	9	6
Irrigation		12	3	3	9	9	7	9	12	9	6	9	9	9	12	6	9	12	9
Mean		9	10	3	6	7		11	10	5	6	8		7	9	4	8	10	
SE[1]		25	3					4	1					1	1				
Control	blue grama	9	6	14	18	6	10	3	11	9	6	6	7	9	26	14	6	14	14
Reduced		9	6	9	3	3	6	6	6	6	9	3	6	9	6	6	3	3	5
Irrigation		6	6	12	6	6	7	6	3	20	11	6	9	6	6	26	6	9	10
Mean		8	6	12	9	5		5	6	11	9	5		8	13	15	5	9	
SE[1]		10	2					17	3					43	4				
Control	needle-and-thread	9	9	3	3	6	6	9	6	6	9	9	8	12	6	6	9	6	8
Reduced		6	12	6	-3	9	7	6	12	9	6	9	8	9	12	9	18	6	11
Irrigation		6	12	3	3	6	6	12	6	9	9	9	9	6	6	18	12	9	10
Mean		7	11	4	3	7		9	8	8	8	9		9	8	11	13	7	
SE[1]		2	1					6	2					16	2				
Control	bare ground	3	3	3	56	56	24	11	3	3	44	50	22	6	3	6	32	63	22
Reduced		3	9	3	74	50	28	3	12	6	38	62	24	14	9	3	41	74	28
Irrigation		14	6	14	44	56	27	6	9	9	44	44	22	6	3	14	44	38	21
Mean		6	6	6	58	54		6	8	6	42	52		9	5	8	39	58	
SE[1]		72	5					32	3					82	6				
Control	litter	18	23	38	6	9	19	29	26	38	12	9	23	26	23	29	6	3	17
Reduced		29	23	49	12	14	26	32	23	44	9	21	26	35	62	50	12	18	35
Irrigation		6	12	32	9	6	13	12	12	18	3	3	9	26	6	9	9	3	10
Mean		18	19	40	9	10		24	20	33	8	11		29	30	29	9	8	
SE[1]		19	3					21	3					121	7				

[1] Within cover components the first value is standard error for sward disturbance and second value is standard error for precipitation treatment.

Appendix A, Table 3. Canopy cover of plants in 4 months for 3 precipitation treatments and 5 sward disturbances at Dundurn in 1998.

Precipitation treatment	Cover component	May						Jun						Jul					
		Sward treatment																	
		Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean
		Canopy cover (%)																	
Control	Total	26	43	36	32	29	32	25	29	22	39	32	29	35	34	32	27	34	32
Reduced		45	32	22	32	35	32	41	22	29	40	26	31	35	29	34	35	37	33
Irrigation		56	41	35	38	39	42	45	31	44	36	37	38	45	39	32	31	35	36
Mean		42	39	31	34	34		30	26	34	30	35		36	34	34	28	37	
SE[1]		52	4					41	4					37	4				
Control	Total forbs	8	19	15	11	11	13	4	8	4	13	11	8	11	5	9	9	10	9
Reduced		15	11	4	8	8	9	15	4	8	14	8	10	11	11	13	11	11	12
Irrigation		15	11	11	11	15	13	15	4	15	0	11	9	9	15	11	4	8	9
Mean		13	14	10	10	11		4	4	11	0	13		8	10	12	5	11	
SE[1]		15	2					32	3					12	2				
Control	clubmoss	15	12	14	3	3	9	15	15	11	3	3	9	15	12	9	3	3	8
Reduced		14	15	12	9	3	11	9	9	9	3	3	6	11	21	12	3	3	10
Irrigation		12	12	11	3	3	8	6	18	9	6	3	8	12	15	6	6	3	8
Mean		14	13	13	5	3		10	14	10	4	3		13	16	9	4	3	
SE[1]		3	1					8	2					7	2				
Control	Total graminoids graminoids	18	24	21	21	18	19	21	21	18	26	21	21	24	29	23	18	24	23
Reduced		30	21	18	24	27	23	26	18	21	26	18	21	24	18	21	24	26	21
Irrigation		41	30	24	27	24	29	30	27	29	36	26	29	36	24	21	27	27	27
Mean		29	25	21	24	23		26	22	23	30	22		28	24	22	23	26	
SE[1]		27	3					7	2					27	3				
Control	Junegrass	9	6	9	12	6	8	6	9	3	14	9	8	9	12	6	12	15	11
Reduced		9	9	3	9	9	8	6	6	6	6	6	6	3	9	3	9	14	7
Irrigation		6	12	9	12	6	9	6	12	6	15	9	9	9	6	6	12	6	8
Mean		8	9	7	11	7		6	9	5	12	8		7	9	5	11	12	
SE[1]		7	2					6	1					9	2				
Control	blue grama	6	12	6	3	9	7	9	9	3	3	6	6	6	14	14	3	3	8
Reduced		18	9	6	6	9	9	14	3	6	14	9	9	18	6	9	3	6	8
Irrigation		29	12	6	9	15	14	18	6	14	9	14	12	18	9	6	9	12	11
Mean		17	11	6	6	11		14	6	8	9	10		14	10	10	5	7	
SE[1]		21	3					15	2					25	3				
Control	needle-and-thread	3	6	6	6	3	4	6	3	12	9	6	7	9	3	3	3	6	4
Reduced		3	3	9	9	9	6	6	9	9	6	3	6	3	3	9	12	6	6
Irrigation		6	6	9	6	3	6	6	9	9	12	3	8	9	9	9	6	9	8
Mean		4	5	8	7	5		6	7	10	9	4		7	5	7	7	7	
SE[1]		5	1					6	2					11	2				
Control	bare ground	3	3	6	56	21	18	6	11	3	38	32	18	11	3	3	65	32	23
Reduced		3	3	9	62	9	17	3	6	11	44	29	18	3	6	3	50	33	19
Irrigation		3	3	3	56	23	17	3	3	3	26	27	12	6	11	9	38	38	20
Mean		3	3	6	58	18		4	6	5	36	29		6	6	5	51	34	
SE[1]		18	3					17	2					50	4				
Control	Litter	44	50	38	21	44	39	56	35	44	12	21	34	26	18	38	9	21	22
Reduced		44	38	38	15	44	36	62	36	53	9	27	41	35	41	62	14	18	34
Irrigation		32	29	32	21	21	27	38	38	38	24	18	31	32	26	38	18	6	24
Mean		40	39	36	19	36		52	43	45	15	22		31	28	46	14	15	
SE[1]		35	4					64	5					49	4				

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[1] Within cover components the first value is standard error for sward disturbance and second value is standard error for precipitation treatment.

Appendix A, Table 4. Probabilities that contrasts of mean soil water in the 0-30 cm depth for 8 dates are different among 3 precipitation amounts and 5 sward disturbances at Dundurn for plots disturbed in April 1997. Bold values indicate means are different ($P \leq 0.05$).

	Date of determination								
	May		Jun.		Jul.		Aug.		
Treatment contrast	9	20	9	26	8	26	5	21	Mean
	Probability								
Aw^1*Cw^2 vs. Cs^3* CR^4	0.885	0.264	0.397	0.749	0.972	0.727	0.294	0.525	0.845
Aw*Cw vs. K^5* CR	0.688	**0.033**	0.586	0.451	0.245	0.727	0.218	0.338	0.165
Aw*Cw vs. Cs* K	0.586	0.287	0.168	0.663	0.232	0.487	0.852	0.745	0.231
Aw*Cw vs. N^6* Cs	0.371	0.849	0.062	0.758	0.740	0.884	0.901	0.989	0.364
Aw*Cw vs. M^7* Cs	0.962	0.557	0.059	0.106	0.807	0.082	0.495	0.745	0.259
Aw* Cw vs. M* N	0.397	0.438	0.981	0.187	0.930	0.109	0.421	0.755	0.822
Rw^8*Cw vs. Cs* CR	0.232	0.319	0.545	**0.049**	0.129	0.237	0.421	0.661	0.140
Rw*Cw vs. K*CR	0.860	**0.045**	0.107	0.179	0.206	0.977	0.059	0.397	0.082
Rw*Cw vs. Cs* K	0.307	0.295	0.305	0.514	0.793	0.226	0.267	0.202	0.783
Rw*Cw vs. N* Cs	0.748	0.125	**0.018**	0.827	0.530	0.954	0.756	0.073	0.200
Rw*Cw vs. M* Cs	0.315	0.756	0.732	0.385	0.206	0.434	0.294	0.311	0.578
Rw*Cw vs. M* N	0.187	0.067	**0.038**	0.514	0.519	0.469	0.176	0.421	0.070
Aw*Rw vs. Cs* CR	0.182	0.904	0.150	0.096	0.121	0.129	0.804	0.285	0.198
Aw*Rw vs. K* CR	0.822	0.890	0.278	0.547	0.916	0.706	0.495	0.910	0.713
Aw*Rw vs. Cs*K	0.121	0.986	0.716	0.279	0.147	0.060	0.354	0.338	0.354
Aw* Rw vs. N*Cs	0.564	0.177	0.594	0.599	0.339	0.839	0.852	0.075	0.703
Aw* Rw vs. M*Cs	0.292	0.782	0.112	**0.015**	0.133	**0.014**	0.709	0.489	0.095
Aw* Rw vs. M* N	0.630	0.279	**0.036**	0.052	0.576	**0.022**	0.577	0.267	**0.043**

[1] precipitation added

[2] control no precipitation manipulation.

[3] control no sward disturbance.

[4] clubmoss removed

[5] clubmoss killed

[6] nitrogen added

[7] mechanical disturbance

[8] precipitation reduced

Appendix A, Table 5. Probabilities that contrasts of mean mid-day leaf xylem water potential of Junegrass or blue grama on 8 dates for 3 precipitation amounts and 5 sward disturbances at Dundurn for plots disturbed in April 1997. Bold values indicate means are different ($P \leq 0.05$).

	Junegrass				blue grama				
	Date of determination								
	May		Jun.		Jul.		Aug.		
Treatment contrast	9	20	9	26	8	26	5	21	Mean
	Probability								
Aw^{1}*Cw^{2} vs. Cs^{3}* CR^{4}	**0.017**	0.060	0.582	0.443	0.244	1.000	0.878	**0.017**	0.324
Aw*Cw vs. K^{5}* CR	0.229	0.140	0.115	0.215	0.634	0.707	0.927	**0.044**	0.928
Aw*Cw vs. Cs* K	0.208	0.670	0.298	0.631	0.487	0.707	0.807	0.680	0.370
Aw*Cw vs. N^{6}* Cs	0.252	0.670	0.956	0.502	0.443	0.574	0.903	0.219	0.918
Aw*Cw vs. M^{7}* Cs	0.055	0.395	0.826	0.885	0.971	0.639	0.878	**0.027**	0.969
Aw* Cw vs. M* N	0.421	0.204	0.869	0.597	0.465	0.925	0.783	0.305	0.529
Rw^{8}*Cw vs. Cs* CR	0.817	0.943	0.869	0.773	0.112	0.950	0.807	0.836	0.419
Rw*Cw vs. K*CR	0.252	0.722	0.783	0.847	0.325	0.851	0.737	0.119	0.969
Rw*Cw vs. Cs* K	0.171	0.776	0.912	0.631	0.534	0.900	0.927	0.173	0.397
Rw*Cw vs. N* Cs	0.389	0.619	0.351	0.502	0.797	0.851	0.110	0.492	0.748
Rw*Cw vs. M* Cs	0.154	0.435	0.509	0.252	0.180	0.900	0.104	0.582	0.057
Rw*Cw vs. M* N	**0.025**	0.776	0.783	0.073	0.275	0.754	0.976	0.890	0.110
Aw*Rw vs. Cs* CR	**0.029**	0.051	0.475	0.631	0.660	0.950	0.927	**0.027**	0.857
Aw*Rw vs. K* CR	**0.022**	0.070	0.066	0.154	0.608	0.574	0.669	0.630	0.898
Aw*Rw vs. Cs*K	0.908	0.887	0.251	0.338	0.942	0.617	0.737	0.079	0.959
Aw* Rw vs. N*Cs	**0.048**	0.357	0.380	0.182	0.608	0.707	0.087	0.059	0.827
Aw* Rw vs. M*Cs	0.604	0.943	0.660	0.315	0.191	0.553	0.139	**0.007**	0.062
Aw* Rw vs. M* N	0.139	0.322	0.660	**0.022**	0.072	0.827	0.807	0.373	0.097

[1] precipitation added

[2] control no precipitation manipulation.

[3] control no sward disturbance.

[4] clubmoss removed

[5] clubmoss killed

[6] nitrogen added

[7] mechanical disturbance

[8] precipitation reduced

Appendix A , Table 6. Probabilities that contrasts of mean soil water in the 0-30 cm depth are different on 8 dates among 3 precipitation amounts and 5 sward disturbances at Rudy for plots disturbed in April 1998. Bold values indicate means are different ($P \leq 0.05$).

	Date of determination								
	May		Jun.		Jul.		Aug.		
Treatment contrast	7	21	11	25	9	28	7	18	Mean
	Probability								
Aw[1]*Cw[2] vs. Cs[3]* CR[4]	0.30	0.783	0.763	0.738	0.53	0.376	0.124	0.44	0.659
Aw*Cw vs. K[5]* CR	**0.03**	0.107	0.897	0.625	0.42	0.285	0.109	0.42	0.799
Aw*Cw vs. Cs* K	0.24	0.179	0.863	0.877	0.85	0.851	0.948	0.12	0.487
Aw*Cw vs. N[6]* Cs	0.40	0.702	0.415	0.504	0.95	0.210	0.948	**0.00**	0.425
Aw*Cw vs. M[7]* Cs	0.73	0.375	0.763	0.390	0.63	0.306	0.948	0.90	0.399
Aw* Cw vs. M* N	0.61	0.611	0.266	0.847	0.67	0.815	1.000	**0.01**	0.105
Rw[8]*Cw vs. Cs* CR	0.95	0.915	0.304	0.709	0.17	0.779	0.845	0.98	0.678
Rw*Cw vs. K*CR	0.14	0.207	1.000	0.343	0.47	0.607	0.301	0.40	0.596
Rw*Cw vs. Cs* K	0.15	0.247	0.304	0.562	0.51	0.815	0.400	0.39	0.346
Rw*Cw vs. N* Cs	0.10	0.222	0.249	**0.033**	0.75	0.265	0.074	**0.01**	0.975
Rw*Cw vs. M* Cs	0.90	0.750	0.266	0.418	**0.01**	0.674	1.000	0.51	0.321
Rw*Cw vs. M* N	0.07	0.126	**0.027**	0.172	**0.02**	0.128	0.074	**0.00**	0.306
Aw*Rw vs. Cs* CR	0.32	0.865	0.186	0.479	0.45	0.544	0.176	0.45	0.393
Aw*Rw vs. K* CR	0.47	0.718	0.897	0.154	0.93	0.575	0.559	0.97	0.434
Aw*Rw vs. Cs*K	0.78	0.848	0.232	0.464	0.40	0.963	0.436	0.47	0.106
Aw* Rw vs. N*Cs	0.41	0.398	0.731	0.133	0.70	0.888	0.064	0.79	0.443
Aw* Rw vs. M*Cs	0.64	0.230	0.415	0.959	**0.00**	0.152	0.948	0.44	0.880

[1] precipitation added

[2] control no precipitation manipulation.

[3] control no sward disturbance.

[4] clubmoss removed

[5] clubmoss killed

[6] nitrogen added

[7] mechanical disturbance

[8] precipitation reduced

Appendix A, Table 7. Probabilities that contrasts of mean mid-day leaf xylem water potentials of Junegrass or blue grama are different on 8 dates among 3 precipitation amounts and 5 sward disturbances at Rudy for plots disturbed in April 1998. Bold values indicate means are different ($P \leq 0.05$).

	Junegrass				blue grama				
	Date of determination								
	May		Jun.		Jul.		Aug.		
Treatment contrast	7	21	11	25	9	28	7	18	Mean
	Probability								
Aw[1]*Cw[2] vs. Cs[3]* CR[4]	0.491	0.069	0.644	0.525	0.790	0.946	**0.041**	0.727	0.612
Aw*Cw vs. K[5]* CR	0.209	0.045	0.644	0.603	0.081	0.950	0.420	0.688	0.830
Aw*Cw vs. Cs* K	0.565	0.848	0.357	0.908	0.137	0.995	0.202	0.957	0.471
Aw*Cw vs. N[6]* Cs	0.172	0.339	0.829	**0.042**	0.252	0.852	0.803	0.470	0.567
Aw*Cw vs. M[7]* Cs	0.908	0.523	0.538	0.772	0.426	0.985	0.233	0.393	0.724
Aw* Cw vs. M* N	0.209	0.115	0.407	**0.021**	0.723	0.838	0.151	0.119	0.825
Rw[8]*Cw vs. Cs* CR	0.818	0.372	0.712	0.488	0.137	0.098	0.125	0.688	**0.026**
Rw*Cw vs. K*CR	0.954	0.129	0.095	0.098	0.929	0.083	0.202	0.160	0.089
Rw*Cw vs. Cs* K	0.863	0.523	**0.044**	**0.021**	0.116	0.936	0.787	0.311	0.571
Rw*Cw vs. N* Cs	0.908	0.146	0.479	0.275	0.161	0.906	0.740	0.423	0.914
Rw*Cw vs. M* Cs	0.773	0.798	0.121	0.137	0.723	0.847	0.983	**0.001**	0.646
Rw*Cw vs. M* N	0.863	0.089	0.390	0.685	0.290	0.941	0.756	**0.012**	0.571
Aw*Rw vs. Cs* CR	0.645	0.339	0.926	0.954	0.081	0.085	0.590	0.957	0.079
Aw*Rw vs. K* CR	0.230	0.609	0.222	**0.032**	0.097	0.073	0.633	0.311	0.057
Aw*Rw vs. Cs*K	0.455	0.654	0.258	**0.028**	0.929	0.941	0.312	0.337	0.876
Aw* Rw vs. N*Cs	0.209	**0.019**	0.357	0.328	0.790	0.761	0.934	0.131	0.641
Aw* Rw vs. M*Cs	0.863	0.372	0.342	0.078	0.658	0.862	0.225	**0.014**	0.418
Aw* Rw vs. M* N	0.155	**0.002**	0.975	**0.008**	0.479	0.896	0.257	0.310	0.729

[1] precipitation added

[2] control no precipitation manipulation.

[3] control no sward disturbance.

[4] clubmoss removed

[5] clubmoss killed

[6] nitrogen added

[7] mechanical disturbance

[8] precipitation reduced

Appendix A, Table 8. Probabilities that contrasts of mean soil water in the 0-30 cm depth are different on 8 dates among 3 precipitation amounts and 5 sward disturbances at Dundurn for plots disturbed in April 1997. Bold values indicate means are different ($P \leq 0.05$).

	Date of determination								
	May		Jun.		Jul.		Aug.		
Treatment contrast	7	21	11	25	9	28	7	18	Mean
	Probability								
Aw^{1}*Cw^{2} vs. Cs^{3}* CR^{4}	0.696	0.428	0.501	0.450	0.951	0.616	1.000	0.985	0.519
Aw*Cw vs. K^{5}* CR	0.672	0.512	0.653	0.714	0.882	0.969	0.807	**0.039**	0.114
Aw*Cw vs. Cs* K	0.974	0.890	0.822	0.696	0.931	0.590	0.807	**0.037**	0.341
Aw*Cw vs. N^{6}* Cs	0.720	0.193	0.388	0.346	0.990	0.700	0.592	0.956	0.214
Aw*Cw vs. M^{7}* Cs	0.089	0.389	0.162	0.724	0.814	0.488	0.845	0.511	0.447
Aw* Cw vs. M* N	0.176	**0.034**	**0.027**	0.554	0.804	0.283	0.733	0.477	0.623
Rw^{8}*Cw vs. Cs* CR	0.922	1.000	0.405	0.668	0.324	0.847	0.309	0.572	0.658
Rw*Cw vs. K*CR	0.515	0.352	0.773	0.650	0.951	0.110	0.103	0.268	0.398
Rw*Cw vs. Cs* K	0.455	0.352	0.586	0.980	0.355	0.075	**0.010**	0.584	0.685
Rw*Cw vs. N* Cs	0.536	0.428	0.521	0.810	0.496	0.908	0.661	1.000	0.059
Rw*Cw vs. M* Cs	0.300	0.230	0.424	0.554	0.747	0.267	0.192	0.037	0.222
Rw*Cw vs. M* N	0.672	0.678	0.872	0.724	0.719	0.221	0.382	**0.037**	**0.003**
Aw*Rw vs. Cs* CR	0.769	0.428	0.872	0.743	0.295	0.758	0.309	0.559	0.839
Aw*Rw vs. K* CR	0.285	0.782	0.872	0.930	0.833	0.119	0.162	0.317	0.452
Aw*Rw vs. Cs*K	0.436	0.286	0.748	0.677	0.401	0.207	**0.018**	0.117	0.582
Aw* Rw vs. N*Cs	0.794	**0.040**	0.136	0.481	0.504	0.787	0.332	0.956	0.500
Aw* Rw vs. M*Cs	0.495	0.729	0.542	0.810	0.578	0.671	0.136	0.144	0.051

[1] precipitation added

[2] control no precipitation manipulation.

[3] control no sward disturbance.

[4] clubmoss removed

[5] clubmoss killed

[6] nitrogen added

[7] mechanical disturbance

[8] precipitation reduced

Appendix A, Table 9. Probabilities that contrasts of mean mid-day leaf xylem water potentials of Junegrass or blue grama are different on 8 dates among 3 precipitation amounts and 5 sward disturbances at Dundurn in 1998. Bold values indicate means are different ($P \leq 0.05$).

	Junegrass				blue grama				
	Date of determination								
	May		Jun.		Jul.		Aug.		
Treatment contrast	7	21	11	25	9	28	7	18	Mean
	Probability								
Aw[1]*Cw[2] vs. Cs[3]* CR[4]	0.357	0.509	0.511	0.885	0.979	0.697	0.980	0.810	0.803
Aw*Cw vs. K[5]* CR	0.902	0.115	0.536	0.840	0.937	0.867	0.115	0.426	0.803
Aw*Cw vs. Cs* K	0.297	0.351	0.969	0.954	0.916	0.824	0.110	0.576	0.619
Aw*Cw vs. N[6]* Cs	1.000	0.582	0.757	0.818	0.874	0.541	0.214	0.823	0.513
Aw*Cw vs. M[7]* Cs	0.666	0.783	0.786	0.818	0.958	**0.020**	1.000	0.205	0.497
Aw* Cw vs. M* N	0.666	0.410	0.969	0.645	0.833	0.080	0.214	0.138	0.186
Rw[8]*Cw vs. Cs* CR	0.460	0.825	0.168	0.751	1.000	0.470	0.462	0.119	0.078
Rw*Cw vs. K*CR	**0.031**	0.956	0.087	0.729	0.874	0.911	0.049	0.435	0.539
Rw*Cw vs. Cs* K	0.144	0.869	0.728	0.977	0.874	0.405	0.205	**0.022**	**0.020**
Rw*Cw vs. N* Cs	0.357	0.380	1.000	0.818	0.874	0.405	0.353	0.150	0.291
Rw*Cw vs. M* Cs	0.902	0.545	0.728	0.863	0.853	0.697	0.159	0.287	0.158
Rw*Cw vs. M* N	0.297	0.783	0.728	0.954	0.979	0.224	**0.022**	0.701	0.714
Aw*Rw vs. Cs* CR	0.101	0.659	0.463	0.863	0.979	0.738	0.447	0.184	0.127
Aw*Rw vs. K* CR	**0.041**	0.128	0.265	0.885	0.937	0.780	0.676	0.119	0.714
Aw*Rw vs. Cs*K	0.666	0.273	0.699	0.977	0.958	0.541	0.731	**0.005**	0.061
Aw* Rw vs. N*Cs	0.357	0.741	0.757	1.000	1.000	0.152	**0.033**	0.222	0.685
Aw* Rw vs. M*Cs	0.758	0.380	0.938	0.687	0.812	**0.050**	0.159	**0.023**	**0.040**
Aw* Rw vs. M* N	0.538	0.582	0.699	0.687	0.812	0.578	**0.001**	0.266	0.094

[1] precipitation added

[2] control no precipitation manipulation.

[3] control no sward disturbance.

[4] clubmoss removed

[5] clubmoss killed

[6] nitrogen added

[7] mechanical disturbance

[8] precipitation reduced

Appendix A, Table 10. Probabilities that contrasts of mean graminoid, forb, and total biomass are different for 3 precipitation amounts and 5 sward disturbances at Dundurn in 1997 and at Dundurn and Rudy in 1998. Bold values indicate contrasts are different ($P \leq 0.05$).

	Dundurn						Rudy		
	First growing season			Second growing season			First growing season		
Treatment contrast	Graminoids	Forbs	Total	Graminoids	Forbs	Total	Graminoids	Forbs	Total
	Probability								
Aw[1]*Cw[2] vs. Cs[3]* CR[4]	0.066	**0.042**	**0.034**	0.814	0.355	0.206	0.552	0.602	0.360
Aw*Cw vs. K[5]* CR	0.879	0.246	0.952	0.973	0.738	0.372	**0.040**	0.448	0.179
Aw*Cw vs. Cs* K	**0.047**	0.363	**0.039**	0.788	0.553	0.703	**0.010**	0.811	**0.027**
Aw*Cw vs. N[6]* Cs	**0.034**	0.384	**0.029**	0.638	0.483	0.314	0.158	0.583	0.371
Aw*Cw vs. M[7]* Cs	**0.042**	**0.047**	**0.022**	0.156	0.057	**0.007**	0.744	0.955	0.736
Aw* Cw vs. M* N	0.927	0.251	0.907	0.337	0.217	0.075	0.274	0.545	0.575
Rw[8]*Cw vs. Cs* CR	0.844	0.064	0.885	0.654	**0.024**	0.068	0.196	0.642	0.398
Rw*Cw vs. K*CR	0.924	**0.005**	0.670	0.092	0.191	0.969	0.407	0.622	0.691
Rw*Cw vs. Cs* K	0.919	0.300	0.778	0.209	0.318	0.074	0.637	0.978	0.653
Rw*Cw vs. N* Cs	0.986	0.426	0.901	0.467	0.066	**0.027**	0.719	0.465	0.838
Rw*Cw vs. M* Cs	0.859	0.220	0.962	0.163	0.537	0.123	0.278	0.714	0.213
Rw*Cw vs. M* N	0.845	**0.047**	0.864	0.495	0.214	0.479	0.466	0.275	0.149
Aw*Rw vs. Cs* CR	**0.043**	0.847	**0.047**	0.831	0.167	0.560	0.480	0.326	0.943
Aw*Rw vs. K* CR	0.955	0.083	0.714	0.086	0.326	0.393	**0.005**	0.214	0.084
Aw*Rw vs. Cs*K	**0.038**	0.056	**0.020**	0.130	0.682	0.154	**0.030**	0.789	0.073
Aw* Rw vs. N*Cs	**0.035**	0.100	**0.021**	0.797	0.245	0.211	0.079	0.204	0.488
Aw* Rw vs. M*Cs	**0.028**	0.420	**0.020**	0.982	0.188	0.211	0.161	0.673	0.116 8
Aw* Rw vs. M* N	0.916	0.382	0.957	0.779	**0.016**	**0.015**	0.711	0.093	0.371

[1] precipitation added

[2] control no precipitation manipulation.

[3] control no sward disturbance.

[4] clubmoss removed

[5] clubmoss killed

[6] nitrogen added

[7] mechanical disturbance

[8] precipitation reduced

Appendix A, Table 11. Peak standing crop of graminoids for 3 precipitation treatments and 5 sward disturbances at Dundurn in 1997.

Precipitation treatment	Species	Sward treatment						
		Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]
		Peak standing crop ($g\ m^{-2}$)						
Control	Junegrass	1.3	1.0	4.9	4.3	2.4	2.8	
Reduced		3.5	1.5	2.1	3.4	4.7	3.0	
Irrigation		0.3	3.3	0.9	5.5	4.2	2.9	0.74
Mean		1.7	1.9	2.6	4.4	3.8		0.95
Control	blue grama	10.1	18.0	7.1	8.0	3.2	9.3	
Reduced		10.6	4.4	4.5	5.4	5.5	6.1	
Irrigation		25.8	7.0	12.5	7.1	15.2	13.5	2.46
Mean		15.5	9.8	8.0	6.9	7.9		3.17
Control	needle-and-thread	13.4	5.7	7.2	1.9	7.2	7.1	
Reduced		2.9	10.4	11.9	5.4	3.0	6.7	
Irrigation		5.8	11.1	11.2	2.5	4.7	7.1	1.61
Mean		7.4	9.0	10.1	3.3	5.0		2.08
Control	sheeps fescue	0.0	0.0	0.8	0.0	0.1	0.2	
Reduced		0.3	0.0	0.0	0.0	0.0	0.1	
Irrigation		88.0	1.3	1.6	0.9	0.0	18.4	10.05
Mean		29.4	0.5	0.8	0.3	0.0		12.05
Control	Hooker's oat grass	0.0	0.0	0.0	0.0	0.0	0.0	
Reduced		0.0	0.0	0.4	0.0	0.1	0.1	
Irrigation		0.0	0.0	0.1	0.0	0.0	0.0	0.04
Mean		0.0	0.0	0.2	0.0	0.0		0.05
Control	sand dropseed	0.4	0.0	0.0	0.0	0.0	0.1	
Reduced		0.0	0.0	0.0	0.0	0.0	0.0	
Irrigation		0.0	0.0	0.0	0.0	0.0	0.0	0.05
Mean		0.1	0.0	0.0	0.0	0.0		0.06
Control	sand grass	0.0	0.0	2.0	0.0	0.0	0.4	
Reduced		0.0	0.0	0.0	0.0	0.0	0.0	
Irrigation		0.0	0.0	0.0	0.0	0.0	0.0	0.23
Mean		0.0	0.0	0.7	0.0	0.0		0.29
Control	sedges	0.0	0.3	0.1	0.0	0.0	0.1	
Reduced		0.3	0.3	0.0	0.3	0.8	0.3	
Irrigation		0.0	0.1	0.2	0.0	0.1	0.1	0.09
Mean		0.1	0.2	0.1	0.1	0.3		0.11

[1] Within species the upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

Appendix A, Table 12. Peak standing crop of graminoids for 3 precipitation treatments and 5 sward disturbances in at Rudy in 1998.

		Sward disturbance						
Precipitation treatment	Species	Control	Nitrogen added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]
		Peak standing crop (g m^{-2})						
Control	Junegrass	12.3	13.9	2.7	7.1	8.2	8.8	
Reduced		7.2	6.8	0.5	5.2	14.6	6.9	
Irrigation		4.3	16.2	2.2	5.6	14.5	8.6	1.59
Mean		12.3	12.3	1.8	6.0	12.4		2.05
Control	blue grama	23.0	15.5	8.4	2.5	3.7	10.6	
Reduced		10.9	4.7	10.5	4.7	6.9	7.5	
Irrigation		11.4	19.2	42.5	12.1	5.1	18.1	4.19
Mean		15.1	13.1	20.5	6.4	5.2		5.40
Control	needle-and-thread	9.1	22.4	32.1	35.2	12.5	22.3	
Reduced		25.8	26.8	26.8	10.7	17.2	21.5	
Irrigation		34.2	32.1	38.2	18.3	22.4	29.0	3.96
Mean		27.1	27.1	32.4	21.4	17.4		5.12
Control	sheep fescue	11.3	0.3	4.9	1.2	8.6	5.3	
Reduced		1.7	3.9	0.0	0.8	0.4	1.4	
Irrigation		1.6	2.8	2.7	7.6	0.9	3.1	1.69
Mean		2.3	2.3	2.5	3.2	3.3		2.18
Control	sand grass	2.7	2.6	4.2	15.6	5.3	6.1	
Reduced		1.3	2.2	1.6	1.2	5.3	2.3	
Irrigation		2.2	4.5	6.9	6.5	1.6	4.3	1.56
Mean		3.1	3.1	4.2	7.8	4.1		2.02
Control	Sandberg's bluegrass	0.0	0.7	0.0	0.0	0.7	0.3	
Reduced		0.0	0.0	0.0	0.7	0.0	0.1	
Irrigation		0.0	0.0	0.0	0.0	0.0	0.0	0.10
Mean		0.2	0.2	0.0	0.2	0.2		0.13
Control	plains reedgrass	5.9	19.7	2.2	7.9	7.0	8.5	
Reduced		3.1	3.6	0.5	2.5	6.5	3.2	
Irrigation		8.6	16.3	2.6	15.5	9.6	10.5	3.22
Mean		13.2	13.2	1.8	8.6	7.7		4.16
Control	western wheatgrass	9.8	0.0	0.0	0.9	2.7	2.7	
Reduced		5.5	0.0	0.0	0.2	6.2	2.4	
Irrigation		3.6	0.0	3.5	5.2	0.9	2.6	1.87
Mean		0.0	0.0	1.2	2.1	3.3		2.41
Control	sedges	6.0	5.2	0.3	5.7	4.3	4.3	
Reduced		0.7	0.8	0.9	1.9	0.6	1.0	
Irrigation		5.4	12.1	1.2	3.2	2.2	4.8	1.15
Mean		6.0	6.0	0.8	3.6	2.4		1.49
Control	Baltic rush	0.5	0.4	0.0	0.0	0.0	0.2	
Reduced		0.0	0.0	0.0	0.0	0.0	0.0	
Irrigation		0.0	0.0	5.4	0.4	0.0	1.2	0.63
Mean		0.1	0.1	1.8	0.1	0.0		0.81

[1] Within species the upper value is standard error for precipitation treatments and lower value is standard error for sward disturbance.

Appendix A, Table 13. Peak standing crop of graminoids for 3 precipitation treatments and 5 sward disturbances at Dundurn in 1998.

Precipitation treatment	Species	Control	N added	Clubmoss killed	Mechanical	Clubmoss removed	Mean	Standard error[1]
		---------------	---------------Peak standing crop ($g\ m^{-2}$)	---------------	---------------	---------------		
Control	Junegrass	17.7	14.8	8.2	48.4	20.1	21.8	
Reduced		7.0	10.9	8.5	26.1	16.6	13.8	
Irrigation		7.1	24.7	11.6	21.6	23.3	17.7	3.38
Mean		10.6	16.8	9.4	32.0	20.0		4.37
Control	blue grama	13.5	25.2	29.6	10.2	8.6	17.4	
Reduced		30.2	9.0	2.6	6.7	23.8	14.5	
Irrigation		47.9	12.2	0.0	25.1	35.2	24.1	6.29
Mean		30.5	15.5	10.7	14.0	22.5		8.12
Control	needle-and-thread	16.2	9.1	33.0	33.7	16.5	21.7	
Reduced		5.2	10.2	24.5	21.1	9.3	14.1	
Irrigation		8.6	21.3	85.2	23.2	10.3	29.7	6.75
Mean		10.0	13.5	47.6	26.0	12.0		8.72
Control	sheep fescue	0.0	0.8	3.6	0.0	0.9	1.1	
Reduced		0.0	0.0	3.5	0.6	0.0	0.8	
Irrigation		0.5	0.0	2.2	5.5	0.9	1.8	0.67
Mean		0.2	0.3	3.1	2.0	0.6		0.87
Control	Hooker's oat grass	0.0	0.0	1.1	0.2	0.0	0.3	
Reduced		0.0	0.0	0.2	0.0	0.0	0.0	
Irrigation		0.0	2.1	0.0	0.0	3.0	1.0	0.42
Mean		0.0	0.7	0.4	0.1	1.0		0.54
Control	sand dropseed	0.0	0.0	0.0	0.0	0.6	0.1	
Reduced		0.0	0.0	0.0	0.0	0.0	0.0	
Irrigation		0.0	0.0	0.0	0.0	0.0	0.0	0.07
Mean		0.0	0.0	0.0	0.0	0.2		0.09
Control	Sandberg's bluegrass	0.0	0.0	0.0	0.0	1.5	0.3	
Reduced		0.0	0.0	0.0	0.0	2.8	0.6	
Irrigation		0.0	0.0	0.0	0.0	0.2	0.0	0.26
Mean		0.0	0.0	0.0	0.0	1.5		0.34
Control	plains reedgrass	0.0	0.0	0.0	0.0	0.0	0.0	
Reduced		0.0	0.0	0.2	0.0	0.5	0.1	
Irrigation		0.0	0.6	0.0	0.0	0.6	0.2	0.09
Mean		0.0	0.2	0.1	0.0	0.4		0.12
Control	sedges	1.8	1.8	0.9	1.2	1.1	1.4	
Reduced		1.9	1.1	3.2	1.5	2.3	2.0	
Irrigation		1.3	2.9	1.2	3.0	1.4	2.0	0.40
Mean		1.7	1.9	1.8	1.9	1.6		0.51

[1] Within dates the upper value is standard error for sward disturbance and lower value is standard error for precipitation treatment.

Appendix A, Table 14. Probabilities that contrasts of mean biomass allocation for Junegrass and blue grama at anthesis are different for 3 precipitation amounts and 5 sward disturbances at Dundurn in 1997. Bold values indicate means are different ($P \leq 0.05$).

	Junegrass			blue grama		
	Biomass category					
Treatment contrast	Inflorescence	Culms	total	Inflorescence	Culms	Total
	Probability					
Aw[1]*Cw[2] vs. Cs[3]* CR[4]	0.765	0.716	0.963	0.408	0.710	0.689
Aw*Cw vs. K[5]* CR	0.610	0.336	0.612	0.844	0.862	0.646
Aw*Cw vs. Cs* K	0.420	0.547	0.645	0.527	0.842	0.953
Aw*Cw vs. N[6]* Cs	0.762	0.844	0.274	0.406	0.795	0.704
Aw*Cw vs. M[7]* Cs	0.602	0.473	0.586	0.971	0.244	0.980
Aw* Cw vs. M* N	0.411	0.362	0.578	0.386	0.157	0.686
Rw[8]*Cw vs. Cs* CR	0.651	0.371	0.549	0.776	0.440	0.566
Rw*Cw vs. K*CR	0.853	0.759	0.828	0.063	0.663	0.325
Rw*Cw vs. Cs* K	0.525	0.232	0.416	0.112	0.230	0.678
Rw*Cw vs. N* Cs	0.897	0.493	0.711	0.679	0.798	0.787
Rw*Cw vs. M* Cs	0.699	0.273	0.505	0.884	0.584	0.560
Rw*Cw vs. M* N	0.606	0.078	0.301	0.576	0.423	0.754
Aw*Rw vs. Cs* CR	0.878	0.211	0.519	0.268	0.255	0.862
Aw*Rw vs. K* CR	0.744	0.509	0.772	**0.041**	0.793	0.596
Aw*Rw vs. Cs*K	0.863	0.548	0.722	0.329	0.164	0.722
Aw* Rw vs. N*Cs	0.666	0.379	0.466	0.674	0.996	0.913
Aw* Rw vs. M*Cs	0.366	0.074	0.229	0.913	0.533	0.544
Aw* Rw vs. M* N	0.184	**0.009**	0.630	0.756	0.530	0.474

[1] precipitation added

[2] control no precipitation manipulation.

[3] control no sward disturbance.

[4] clubmoss removed

[5] clubmoss killed

[6] nitrogen added

[7] mechanical disturbance

[8] precipitation reduced

Appendix A, Table 15. Probabilities that contrasts of mean biomass allocation for Junegrass and blue grama at anthesis are different for 3 precipitation amounts and 5 sward disturbances at Rudy in 1998. Bold values indicate means are different ($P \leq 0.05$).

	Junegrass			blue grama		
	Biomass category					
Treatment contrast	Inflorescence	Culms	Total	Inflorescence	Culms	Total
	Probability					
Aw*Cw vs. Cs* CR	0.476	0.347	0.393	0.565	0.905	0.960
Aw*Cw vs. K* CR	**0.026**	**0.031**	**0.021**	0.456	0.466	0.352
Aw*Cw vs. Cs* K	0.121	0.207	0.131	0.190	0.541	0.327
Aw*Cw vs. N* Cs	0.114	0.656	0.242	0.491	0.919	0.763
Aw*Cw vs. M* Cs	0.223	0.347	0.244	0.954	0.986	1.000
Aw* Cw vs. M* N	0.710	0.618	0.995	0.527	0.905	0.763
Rw*Cw vs. Cs* CR	0.561	0.157	0.324	0.730	0.959	0.880
Rw*Cw vs. K*CR	0.760	0.285	0.507	0.422	0.709	0.548
Rw*Cw vs. Cs* K	0.782	0.723	0.744	0.645	0.747	0.652
Rw*Cw vs. N* Cs	0.682	0.521	0.592	0.863	0.456	0.434
Rw*Cw vs. M* Cs	0.790	0.582	0.683	0.645	0.388	0.327
Rw*Cw vs. M* N	0.886	0.927	0.898	0.773	0.905	0.841
Aw*Rw vs. Cs* CR	0.894	0.628	0.893	0.818	0.865	0.920
Aw*Rw vs. K* CR	0.052	0.257	0.090	0.125	0.273	0.129
Aw*Rw vs. Cs*K	0.070	0.109	0.069	0.080	0.352	0.155
Aw* Rw vs. N*Cs	0.237	0.844	0.522	0.390	0.397	0.280
Aw* Rw vs. M*Cs	0.338	0.694	0.446	0.605	0.397	0.327
Aw* Rw vs. M* N	0.819	0.555	0.902	0.730	1.000	0.920

[1] precipitation added

[2] control no precipitation manipulation.

[3] control no sward disturbance.

[4] clubmoss removed

[5] clubmoss killed

[6] nitrogen added

[7] mechanical disturbance

[8] precipitation reduced

Appendix A, Table 16. Probabilities that contrasts of mean biomass allocation for Junegrass and blue grama at anthesis are different for 3 precipitation amounts and 5 sward disturbances at Dundurn in 1998. Bold values indicate means are different ($P \leq 0.05$).

	Junegrass			blue grama		
	Biomass category					
Treatment contrast	Inflorescence	Culms	Total	Inflorescence	Culms	Total
	Probability					
Aw[1]*Cw[2] vs. Cs[3]* CR[4]	0.664	0.906	0.848	0.376	0.108	0.129
Aw*Cw vs. K[5]* CR	0.506	0.796	0.617	0.579	0.337	0.361
Aw*Cw vs. Cs* K	0.274	0.889	0.490	0.739	0.507	0.535
Aw*Cw vs. N[6]* Cs	0.468	0.785	0.588	0.657	0.321	0.361
Aw*Cw vs. M[7]* Cs	0.878	0.419	0.768	**0.031**	**0.003**	**0.003**
Aw* Cw vs. M* N	0.380	0.591	0.805	0.081	**0.033**	**0.031**
Rw[8]*Cw vs. Cs* CR	0.621	0.912	0.819	0.657	0.188	0.238
Rw*Cw vs. K*CR	0.566	0.865	0.684	1.000	0.528	0.608
Rw*Cw vs. Cs* K	0.287	0.953	0.526	0.657	0.486	0.500
Rw*Cw vs. N* Cs	0.321	0.723	0.465	0.269	0.690	0.957
Rw*Cw vs. M* Cs	0.183	0.275	0.204	1.000	0.140	0.228
Rw*Cw vs. M* N	**0.023**	0.151	**0.049**	0.269	0.275	0.249
Aw*Rw vs. Cs* CR	0.951	0.994	0.969	0.657	0.765	0.725
Aw*Rw vs. K* CR	0.927	0.929	0.925	0.579	0.739	0.685
Aw*Rw vs. Cs*K	0.976	0.935	0.956	0.911	0.973	0.957
Aw* Rw vs. N*Cs	0.788	0.935	0.848	0.125	0.550	0.389
Aw* Rw vs. M*Cs	0.237	0.061	0.120	**0.031**	0.095	0.061
Aw* Rw vs. M* N	0.149	0.051	0.082	0.505	0.275	0.295

[1] precipitation added
[2] control no precipitation manipulation.
[3] control no sward disturbance.
[4] clubmoss removed
[5] clubmoss killed
[6] nitrogen added
[7] mechanical disturbance
[8] precipitation reduced.

Appendix A, Table 17. Probabilities that contrasts of mean phenological stage of Junegrass or blue grama are different on 6 dates for 3 precipitation amounts and 5 sward disturbances at Dundurn in 1997. Bold values indicate means are different ($P \leq 0.05$).

	Junegrass			blue grama		
	Date of determination					
	May		Jun.		Jul.	
Treatment contrast	15	23	11	28	11	30
	Probability					
Aw[1]*Cw[2] vs. Cs[3]* CR[4]	0.579	0.638	0.264	0.905	0.881	0.062
Aw*Cw vs. K[5]* CR	1.000	0.638	0.487	0.811	0.488	0.208
Aw*Cw vs. Cs* K	0.579	1.000	0.074	0.720	0.585	0.526
Aw*Cw vs. N[6]* Cs	0.270	0.638	0.393	0.811	0.064	1.000
Aw*Cw vs. M[7]* Cs	0.270	0.638	0.789	0.475	0.842	0.526
Aw* Cw vs. M* N	1.000	0.349	0.556	0.342	**0.041**	0.526
Rw[8]*Cw vs. Cs* CR	0.579	0.638	0.630	1.000	0.277	0.526
Rw*Cw vs. K*CR	1.000	1.000	0.066	0.342	0.117	0.526
Rw*Cw vs. Cs* K	0.579	0.638	0.168	0.342	0.620	1.000
Rw*Cw vs. N* Cs	0.579	0.638	1.000	0.405	**0.023**	0.208
Rw*Cw vs. M* Cs	1.000	0.638	0.630	0.633	0.096	1.000
Rw*Cw vs. M* N	0.579	1.000	0.630	0.720	0.519	0.208
Aw*Rw vs. Cs* CR	1.000	0.349	0.113	0.905	0.347	0.208
Aw*Rw vs. K* CR	1.000	0.638	0.242	0.236	0.373	0.526
Aw*Rw vs. Cs*K	1.000	0.638	0.668	0.193	0.960	0.526
Aw* Rw vs. N*Cs	0.579	1.000	0.393	0.551	0.655	0.208
Aw* Rw vs. M*Cs	0.270	0.349	0.455	0.236	0.064	0.526
Aw* Rw vs. M* N	0.579	0.349	0.915	0.551	0.154	0.062

[1] precipitation added

[2] control no precipitation manipulation.

[3] control no sward disturbance.

[4] clubmoss removed

[5] clubmoss killed

[6] nitrogen added

[7] mechanical disturbance

[8] precipitation reduced

Appendix A, Table 18. Probabilities that contrasts of mean phenological stage of Junegrass or blue grama are different on 6 dates for 3 precipitation amounts and 5 sward disturbances at Rudy in 1998. Bold values indicate means are different ($P \leq 0.05$).

	Junegrass			blue grama		
	Date of determination					
	May	Jun.			Jul.	
Treatment contrast	6	4	23	23	13	27
	Probability					
Aw[1]*Cw[2] vs. Cs[3]* CR[4]	0.056	0.324	1.000	0.867	0.877	0.749
Aw*Cw vs. K[5]* CR	0.249	0.468	0.060	0.208	0.758	1.000
Aw*Cw vs. Cs* K	**0.003**	0.791	0.060	0.273	0.877	0.749
Aw*Cw vs. N[6]* Cs	**0.024**	0.074	1.000	0.443	0.607	0.709
Aw*Cw vs. M[7]* Cs	0.056	0.251	1.000	0.581	0.719	0.831
Aw* Cw vs. M* N	0.065	**0.001**	0.338	**0.000**	0.122	0.632
Rw[8]*Cw vs. Cs* CR	0.676	0.448	1.000	0.443	1.000	0.749
Rw*Cw vs. K*CR	0.710	0.374	0.060	0.142	0.572	0.915
Rw*Cw vs. Cs* K	0.431	0.895	0.060	**0.028**	0.572	0.831
Rw*Cw vs. N* Cs	0.676	0.921	1.000	0.443	0.837	0.957
Rw*Cw vs. M* Cs	0.676	0.791	1.000	0.252	0.959	0.831
Rw*Cw vs. M* N	1.000	0.869	1.000	0.701	0.797	0.873
Aw*Rw vs. Cs* CR	0.130	0.817	1.000	0.351	0.877	1.000
Aw*Rw vs. K* CR	0.431	0.869	1.000	0.828	0.797	0.915
Aw*Rw vs. Cs*K	**0.024**	0.692	1.000	0.252	0.681	0.915
Aw* Rw vs. N*Cs	0.062	0.091	1.000	1.000	0.473	0.749
Aw* Rw vs. M*Cs	0.130	0.374	1.000	0.548	0.681	1.000
Aw* Rw vs. M* N	0.710	0.410	1.000	0.548	0.261	0.749

[1] precipitation added

[2] control no precipitation manipulation.

[3] control no sward disturbance.

[4] clubmoss removed

[5] clubmoss killed

[6] nitrogen added

[7] mechanical disturbance

[8] precipitation reduced

Appendix A, Table 19. Probabilities that contrasts of mean phenological stage of Junegrass or blue grama are different on 6 dates for 3 precipitation amounts and 5 sward disturbances at Dundurn in 1998. Bold values indicate means are different ($P \leq 0.05$).

	Junegrass			blue grama		
	Date of determination					
	May	Jun.			Jul.	
Treatment contrast	6	4	23	23	13	27
	Probability					
Aw[1]*Cw[2] vs. Cs[3]* CR[4]	0.416	0.277	0.948	0.258	0.520	0.360
Aw*Cw vs. K[5]* CR	**0.000**	0.585	0.922	0.067	0.458	0.759
Aw*Cw vs. Cs* K	**0.000**	0.585	0.871	0.465	0.920	0.224
Aw*Cw vs. N[6]* Cs	**0.004**	0.106	0.948	0.985	0.794	0.759
Aw*Cw vs. M[7]* Cs	0.001	0.277	1.000	**0.044**	**0.006**	**0.000**
Aw* Cw vs. M* N	0.068	**0.000**	**0.006**	0.285	0.904	**0.000**
Rw[8]*Cw vs. Cs* CR	0.068	0.585	0.432	0.396	0.337	0.360
Rw*Cw vs. K*CR	**0.000**	0.585	0.480	0.151	0.888	0.759
Rw*Cw vs. Cs* K	**0.028**	1.000	0.935	0.025	0.272	0.541
Rw*Cw vs. N* Cs	0.469	0.277	0.935	0.205	0.547	0.541
Rw*Cw vs. M* Cs	**0.000**	0.585	0.465	0.161	0.182	0.541
Rw*Cw vs. M* N	**0.000**	0.585	0.418	0.889	0.458	1.000
Aw*Rw vs. Cs* CR	0.300	0.106	0.470	0.051	0.113	1.000
Aw*Rw vs. K* CR	0.224	0.277	0.422	0.677	0.547	0.541
Aw*Rw vs. Cs*K	**0.028**	0.585	0.935	0.120	0.317	0.541
Aw* Rw vs. N*Cs	**0.028**	0.585	0.884	0.212	0.389	0.759
Aw* Rw vs. M*Cs	**0.000**	0.585	0.465	**0.001**	0.136	**0.000**
Aw* Rw vs. M* N	**0.000**	1.000	0.382	**0.031**	**0.022**	**0.000**

[1] precipitation added

[2] control no precipitation manipulation.

[3] control no sward disturbance.

[4] clubmoss removed

[5] clubmoss killed

[6] nitrogen added

[7] mechanical disturbance

[8] precipitation reduced

Appendix A, Table 20. Probabilities that contrasts of mean soil nitrogen (NO_3) in the 0-30 cm depth of the profile are different at Dundurn in 1997 and at Dundurn and Rudy in 1998. Bold values indicate means are different ($P<0.05$).

	Dundurn		Rudy
Treatment contrast	First year	Second year	First year
	Probability		
Aw^{1}*Cw^{2} vs. Cs^{3}* CR^{4}	0.198	0.719	0.540
Aw*Cw vs. K^{5}* CR	0.545	0.320	0.199
Aw*Cw vs. Cs* K	0.487	0.179	0.493
Aw*Cw vs. N^{6}* Cs	0.530	0.782	0.515
Aw*Cw vs. M^{7}* Cs	0.706	0.261	0.599
Aw* Cw vs. M* N	0.226	0.200	0.329
Rw^{8}*Cw vs. Cs* CR	0.554	0.848	0.899
Rw*Cw vs. K*CR	0.853	0.402	0.051
Rw*Cw vs. Cs* K	0.438	0.305	0.066
Rw*Cw vs. N* Cs	0.418	0.202	0.617
Rw*Cw vs. M* Cs	0.128	0.473	0.682
Rw*Cw vs. M* N	0.461	0.050	0.366
Aw*Rw vs. Cs* CR	0.479	0.866	0.626
Aw*Rw vs. K* CR	0.431	0.873	0.474
Aw*Rw vs. Cs*K	0.935	0.743	0.233
Aw* Rw vs. N*Cs	0.854	0.123	0.879
Aw* Rw vs. M*Cs	0.244	0.680	0.353
Aw* Rw vs. M* N	0.324	0.253	0.435

[1] precipitation added
[2] control no precipitation manipulation.
[3] control no sward disturbance.
[4] clubmoss removed
[5] clubmoss killed
[6] nitrogen added
[7] mechanical disturbance
[8] precipitation reduced

Appendix B

Appendix B, Table 1. Probabilities that contrasts of mean soil water in the 0-3 cm depth of the profile are different on 4 days in plots with clubmoss present or removed following addition of 0-25 mm of water in 3 months in 1997. Bold values indicate contrasts are significantly different ($P \leq 0.05$).

Clubmoss treatment	Precipitation (mm)	May					Jun.					Jul.				
		Time following irrigation (days)														
		0^1	1	2	4	7	0^1	1	2	4	7	0^1	1	2	4	7
		Probability														
Present	0.0 vs. 2.5	**0.046**	0.159	0.410	0.617	**0.024**	0.477	0.657	0.918	0.398	0.784	0.877	**0.000**	0.236	0.449	0.720
	0.0 vs. 5.0	**0.060**	0.432	0.478	0.766	0.062	0.684	0.598	0.618	0.987	0.939	0.951	**0.000**	0.290	0.421	0.525
	0.0 vs. 10.0	0.781	0.065	0.363	0.882	0.302	0.742	0.577	0.630	0.901	0.946	0.326	**0.000**	0.114	0.307	0.707
	0.0 vs. 15.0	0.283	0.694	0.908	0.969	**0.015**	0.465	0.968	0.697	0.794	0.847	0.877	**0.022**	**0.004**	0.924	**0.014**
	0.0 vs. 20.0	0.200	0.325	0.458	0.821	0.145	0.269	0.902	0.525	0.962	0.498	0.666	0.787	**0.007**	0.172	**0.022**
	0.0 vs. 25.0	0.572	0.547	0.273	0.860	0.094	0.662	0.790	0.461	0.776	0.769	0.951	0.805	**0.001**	0.919	**0.001**
Absent																
	0.0 vs. 2.5	0.467	0.147	0.586	0.125	**0.015**	0.219	0.048	0.123	0.446	0.704	0.233	**0.000**	0.182	0.418	0.896
	0.0 vs. 5.0	0.953	0.283	0.935	0.503	**0.035**	0.345	0.326	0.787	0.351	0.630	0.853	**0.002**	0.883	0.551	0.602
	0.0 vs. 10.0	0.064	0.180	0.645	0.965	0.079	0.059	**0.003**	**0.016**	**0.036**	0.062	0.734	**0.000**	0.174	0.830	0.175
	0.0 vs. 15.0	0.260	**0.012**	0.388	0.886	0.272	0.840	0.587	0.246	0.606	0.679	0.283	**0.028**	**0.016**	0.247	**0.037**
	0.0 vs. 20.0	0.539	**0.011**	0.792	0.210	0.132	0.183	0.054	0.116	0.100	0.306	0.257	0.482	**0.000**	0.178	**0.009**
	0.0 vs. 25.0	0.736	0.231	0.547	0.336	0.071	**0.004**	0.020	**0.021**	0.061	0.152	0.600	0.925	**0.000**	0.156	**0.030**

[1] Pre-irrigation treatment.

Appendix B, Table 2. Probabilities that contrasts of mean soil water in the 3-30 cm depth of the profile are different on 4 days in plots with clubmoss present or removed following addition of 0-25 mm of precipitation in 3 months in 1997. Bold values indicate contrasts are significantly different ($P \leq 0.05$).

Precipitation (mm)	May					Jun.					Jul.				
	Time following irrigation (days)														
	0^1	1	2	4	7	0^1	1	2	4	7	0^1	1	2	4	7
	Probability														
	Clubmoss present														
0.0 vs. 2.5	**0.012**	0.141	**0.028**	**0.005**	0.626	0.866	0.547	0.346	0.942	0.893	**0.014**	0.971	0.405	0.745	0.965
0.0 vs. 5.0	0.056	0.292	0.607	**0.036**	0.501	0.556	0.372	0.222	0.847	0.666	**0.013**	0.971	0.447	0.665	0.536
0.0 vs. 10.0	0.218	0.899	0.432	0.133	0.822	0.768	0.691	0.614	0.891	0.964	**0.015**	0.064	**0.000**	0.187	0.312
0.0 vs. 15.0	0.068	0.185	0.197	**0.018**	0.370	0.606	0.895	0.498	0.942	0.710	**0.014**	**0.005**	**0.000**	**0.004**	**0.006**
0.0 vs. 20.0	0.122	0.596	0.945	0.285	0.764	0.113	0.143	0.073	0.705	0.205	**0.018**	**0.003**	**0.000**	**0.000**	**0.000**
0.0 vs. 25.0	**0.043**	0.249	0.561	0.186	0.280	0.315	0.860	0.432	0.790	0.882	**0.005**	**0.002**	**0.000**	**0.002**	**0.012**
	Clubmoss absent														
0.0 vs. 2.5	**0.038**	0.303	0.291	0.124	**0.024**	0.230	0.102	0.075	0.552	0.398	0.671	0.445	0.716	0.540	0.929
0.0 vs. 5.0	**0.029**	0.220	**0.010**	0.163	0.332	0.263	0.237	0.135	0.260	0.274	0.946	0.560	0.771	0.589	0.894
0.0 vs. 10.0	**0.025**	0.340	0.412	0.505	0.708	**0.033**	**0.004**	**0.008**	0.234	0.077	0.911	0.310	0.221	0.096	0.075
0.0 vs. 15.0	0.072	0.185	0.276	0.225	0.130	0.621	0.380	**0.006**	0.717	0.390	0.946	0.688	0.087	0.061	**0.047**
0.0 vs. 20.0	**0.004**	0.315	0.165	0.941	0.940	0.151	**0.039**	0.103	0.450	0.226	0.893	0.328	**0.000**	**0.006**	**0.002**
0.0 vs. 25.0	0.122	0.686	0.918	0.505	0.970	0.094	**0.012**	**0.018**	0.365	0.146	0.929	**0.000**	**0.000**	**0.018**	**0.032**

[1] Pre-irrigation treatment.

Appendix B, Table 3. Probabilities that contrasts of mean mid-day leaf xylem water potentials are different for Junegrass in May and June and for blue grama in July 1997 following addition of 0-25 mm of precipitation on plots with clubmoss present or removed. Bold values indicate contrasts are different ($P \leq 0.05$).

Precipitation treatment (mm)	May					Jun.					Jul.				
	Time following irrigation (days)														
	0[1]	1	2	4	7	0[1]	1	2	4	7	0[1]	1	2	4	7
	Probability														
	Clubmoss present														
0.0 vs. 2.5	0.226	0.059	0.328	0.250	0.206	0.538	0.594	0.542	0.764	0.703	0.712	**0.001**	0.877	0.511	0.585
0.0 vs. 5.0	0.861	0.228	0.759	0.816	0.267	0.681	0.879	0.201	0.707	0.647	0.806	**0.000**	**0.003**	0.233	0.612
0.0 vs. 10.0	0.794	0.079	0.500	0.643	0.030	0.608	0.647	0.684	0.652	0.403	0.272	**0.000**	**0.000**	**0.017**	0.668
0.0 vs. 15.0	0.727	0.022	0.062	0.441	**0.012**	0.473	0.174	0.456	0.548	0.879	0.951	**0.000**	**0.001**	**0.001**	0.371
0.0 vs. 20.0	0.930	0.286	0.426	0.488	0.235	0.758	0.493	**0.047**	0.499	0.289	0.759	**0.000**	**0.000**	**0.008**	0.056
0.0 vs. 25.0	0.930	0.121	0.806	0.537	1.000	0.307	0.594	0.379	0.821	0.939	0.667	**0.000**	**0.000**	**0.010**	0.459
	Clubmoss absent														
0.0 vs. 2.5	0.073	0.091	0.391	0.059	0.811	1.000	0.403	0.498	0.880	0.760	0.299	**0.053**	**0.022**	**0.074**	0.845
0.0 vs. 5.0	0.930	0.202	0.462	0.757	0.426	0.837	0.199	0.838	0.707	0.594	0.759	**0.043**	0.203	0.462	0.969
0.0 vs. 10.0	0.727	0.775	0.426	0.250	0.426	0.758	0.053	0.786	0.707	0.073	0.328	**0.000**	**0.000**	0.439	0.459
0.0 vs. 15.0	0.861	0.520	0.581	0.938	0.811	0.262	0.447	0.635	0.499	0.879	0.462	**0.000**	**0.000**	0.156	0.938
0.0 vs. 20.0	0.794	0.202	0.902	0.699	0.099	0.681	0.289	0.498	0.296	0.594	0.759	**0.000**	**0.000**	**0.053**	0.585
0.0 vs. 25.0	0.663	0.228	0.272	0.877	0.577	0.608	0.447	0.417	0.880	0.226	0.462	**0.000**	**0.000**	**0.022**	0.938

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[1] Pre-irrigation treatment.

Appendix B, Table 4. Probabilities that contrasts of mean soil water in the 0-3 cm depth of the profile are different on 4 days in plots with clubmoss present or removed following addition of 0-25 mm of precipitation in 4 months in 1998. Bold values indicate contrasts are significantly different ($P \leq 0.05$).

Clubmoss treatment	Precipitation (mm)	May					Jun.					Jul.					Aug				
		Time following irrigation (days)																			
		0[1]	1	2	4	7	0[1]	1	2	4	7	0[1]	1	2	4	7	0[1]	1	2	4	7
		Probability																			
Present	0.0 vs. 2.5	**0.006**	0.754	0.525	0.672	0.863	0.387	0.593	0.765	0.758	0.492	0.491	0.906	0.062	0.570	0.736	0.084	**0.048**	0.440	0.300	0.168
	0.0 vs. 5.0	0.812	0.062	0.106	0.179	**0.006**	0.503	**0.003**	0.521	0.128	0.592	0.831	0.492	0.199	0.868	0.194	0.187	**0.038**	**0.060**	0.300	0.056
	0.0 vs. 10.0	0.784	**0.006**	0.131	0.189	0.080	0.650	0.109	**0.067**	**0.044**	0.646	0.484	0.188	0.199	0.584	0.819	0.343	**0.000**	**0.000**	**0.008**	**0.008**
	0.0 vs. 15.0	0.125	**0.003**	**0.001**	0.065	0.062	0.984	**0.000**	**0.008**	0.103	0.232	0.389	0.161	0.173	0.247	0.521	0.238	**0.000**	**0.000**	**0.007**	0.059
	0.0 vs. 20.0	0.770	**0.000**	**0.000**	**0.001**	**0.000**	0.650	**0.003**	**0.002**	0.115	0.247	0.107	0.168	**0.044**	0.331	0.324	0.668	**0.000**	**0.000**	**0.011**	0.102
	0.0 vs. 25.0	0.756	**0.000**	**0.000**	**0.000**	**0.000**	0.120	**0.000**	**0.004**	0.633	0.167	0.964	0.255	0.735	0.698	0.369	0.601	**0.000**	**0.000**	**0.000**	**0.000**
Absent	0.0 vs. 2.5	0.942	0.114	0.870	0.154	**0.017**	0.737	0.487	0.501	0.529	0.702	0.131	0.089	0.470	**0.002**	0.145	1.000	0.755	0.826	0.870	0.857
	0.0 vs. 5.0	0.596	**0.000**	**0.001**	0.093	**0.011**	0.813	0.112	0.200	0.511	0.554	0.240	0.837	0.465	0.052	0.995	**0.016**	**0.009**	0.123	0.106	**0.009**
	0.0 vs. 10.0	0.454	**0.001**	**0.000**	0.141	**0.000**	0.218	**0.001**	**0.001**	0.074	0.218	0.227	0.569	0.068	0.100	0.551	0.634	0.103	0.146	0.090	**0.047**
	0.0 vs. 15.0	0.362	**0.000**	**0.000**	0.081	**0.005**	0.420	**0.000**	**0.000**	0.161	**0.012**	**0.006**	**0.019**	**0.004**	**0.000**	0.148	0.159	**0.000**	**0.000**	**0.000**	**0.004**
	0.0 vs. 20.0	0.402	**0.000**	**0.000**	**0.004**	**0.000**	0.859	**0.000**	**0.001**	0.218	**0.007**	0.169	0.071	0.451	**0.008**	0.264	0.393	**0.000**	**0.000**	**0.000**	**0.001**
	0.0 vs. 25.0	0.186	**0.000**	**0.000**	**0.050**	**0.001**	0.290	**0.000**	**0.001**	0.105	**0.000**	0.331	0.170	0.404	0.211	0.980	0.133	**0.000**	**0.000**	**0.000**	**0.000**

[1] Pre-irrigation treatment.

Appendix B, Table 5. Probabilities that contrasts of mean soil water in the 3-30 cm depth of the profile are different on 4 days in plots with clubmoss present or removed following addition of 0-25 mm of precipitation in 4 months in 1998. Bold values indicate contrasts are significantly different ($P \leq 0.05$).

Precipitation (mm)	May					Jun.					Jul.					Aug.				
	Time following irrigation (days)																			
	0[1]	1	2	4	7	0[1]	1	2	4	7	0[1]	1	2	4	7	0[1]	1	2	4	7
	Probability																			
	Clubmoss present																			
0.0 vs. 2.5	0.249	0.192	0.520	0.204	0.680	0.79	0.548	0.867	0.61	0.844	0.719	0.797	0.126	0.434	0.919	**0.008**	0.631	0.503	0.160	0.250
0.0 vs. 5.0	0.202	0.263	0.432	0.122	0.851	0.89	0.499	0.823	0.92	0.693	0.296	**0.027**	**0.011**	0.225	0.578	**0.028**	0.250	**0.050**	0.069	**0.036**
0.0 vs. 10.0	0.137	0.580	0.592	**0.025**	0.910	0.64	0.151	0.079	0.34	0.409	0.803	0.084	**0.023**	0.661	0.761	0.234	**0.000**	**0.000**	**0.000**	**0.000**
0.0 vs. 15.0	0.452	0.424	0.047	**0.007**	0.296	0.79	**0.001**	**0.006**	0.24	0.172	0.526	0.053	0.091	0.778	0.480	0.089	**0.000**	**0.000**	**0.000**	**0.000**
0.0 vs. 20.0	0.925	0.878	**0.000**	**0.001**	0.148	0.59	**0.002**	**0.004**	**0.02**	**0.032**	0.424	**0.010**	**0.008**	0.552	0.176	0.148	**0.001**	**0.000**	**0.000**	0.250
0.0 vs. 25.0	0.318	0.774	**0.000**	**0.001**	**0.004**	0.79	**0.001**	**0.001**	**0.01**	**0.008**	0.087	**0.002**	**0.001**	0.616	0.082	0.187	**0.000**	**0.000**	**0.000**	**0.000**
	Clubmoss absent																			
0.0 vs. 2.5	0.303	0.894	**0.050**	0.434	0.351	0.18	0.841	0.845	0.90	0.844	0.491	0.128	**0.003**	**0.018**	**0.034**	1.000	0.887	1.000	0.956	0.673
0.0 vs. 5.0	0.416	**0.043**	0.147	**0.008**	**0.048**	0.59	0.468	0.558	0.24	0.161	0.868	0.216	**0.099**	0.096	0.248	0.068	0.086	0.153	**0.018**	**0.010**
0.0 vs. 10.0	0.434	0.352	0.178	0.068	**0.027**	0.46	0.232	**0.001**	0.11	**0.022**	0.544	**0.001**	**0.001**	**0.011**	0.210	0.594	0.299	0.118	0.301	0.250
0.0 vs. 15.0	0.900	0.342	0.336	0.131	0.159	0.59	**0.016**	**0.000**	**0.04**	**0.001**	0.322	**0.000**	**0.008**	**0.009**	**0.048**	0.051	**0.000**	**0.000**	**0.000**	**0.000**
0.0 vs. 20.0	0.275	**0.044**	**0.015**	**0.000**	**0.006**	0.89	**0.000**	**0.001**	**0.00**	**0.001**	0.600	**0.032**	0.107	**0.033**	0.100	0.289	**0.000**	**0.000**	**0.000**	**0.000**
0.0 vs. 25.0	0.950	0.091	**0.005**	**0.010**	**0.001**	0.21	**0.015**	**0.002**	**0.01**	**0.001**	0.393	**0.010**	**0.017**	0.074	0.122	**0.015**	**0.000**	**0.000**	**0.000**	**0.000**

[1] Pre-irrigation treatment.

Appendix B, Table 6. Probabilities that contrasts of mean mid-day leaf xylem water potentials are different for Junegrass in May and June and for blue grama in July and August 1997 following addition of 0-25 mm of precipitation on plots with clubmoss present or removed. Bold values indicate contrasts are different ($P \leq 0.05$).

Clubmoss treatment	Precipitation (mm)	May					Jun.					Jul.					Aug				
		Time following irrigation (days)																			
		0^1	1	2	4	7	0^1	1	2	4	7	0^1	1	2	4	7	0^1	1	2	4	7
		Probability																			
Present	0.0 vs. 2.5	0.499	0.545	0.865	0.693	0.457	0.315	**0.024**	0.462	0.007	0.526	0.857	0.194	0.562	0.904	0.400	0.130	0.537	0.915	0.473	0.811
	0.0 vs. 5.0	0.274	0.229	0.610	0.865	0.852	0.289	**0.009**	0.874	0.807	1.000	0.154	0.793	0.699	0.904	0.629	0.051	0.210	0.260	0.651	0.225
	0.0 vs. 10.0	0.672	0.256	0.552	0.910	0.620	0.140	**0.001**	**0.017**	0.417	0.856	0.718	0.094	0.846	0.548	0.470	0.167	**0.062**	**0.013**	0.506	0.106
	0.0 vs. 15.0	0.799	0.049	0.311	0.735	0.294	0.443	**0.000**	**0.005**	0.569	0.785	0.857	0.297	0.249	1.000	0.337	**0.000**	**0.016**	**0.017**	0.128	0.858
	0.0 vs. 20.0	0.068	0.383	0.352	0.499	0.620	0.296	**0.001**	**0.002**	0.625	0.497	0.052	0.241	0.440	0.810	0.547	**0.018**	**0.010**	**0.009**	0.039	0.084
	0.0 vs. 25.0	0.499	0.420	0.154	0.778	0.077	0.214	**0.005**	0.146	0.807	0.964	1.000	0.041	0.249	0.904	0.035	0.926	**0.006**	**0.006**	0.163	0.058
Absent	0.0 vs. 2.5	0.447	0.460	0.352	0.218	0.901	0.808	**0.007**	**0.036**	0.394	0.260	0.471	0.154	0.087	0.548	0.470	0.001	0.613	0.125	0.076	0.676
	0.0 vs. 5.0	0.096	0.111	0.799	1.000	0.035	0.599	**0.022**	**0.004**	0.569	0.178	0.015	0.793	0.249	0.718	0.629	0.083	0.264	0.324	0.523	0.404
	0.0 vs. 10.0	0.354	0.893	0.671	0.821	0.060	0.716	**0.001**	**0.017**	**0.022**	0.062	0.369	0.513	0.562	0.904	0.904	0.167	0.191	**0.036**	0.065	0.119
	0.0 vs. 15.0	0.799	0.420	0.207	0.312	0.068	0.334	**0.000**	**0.000**	**0.014**	**0.042**	0.211	0.694	0.335	0.630	0.097	0.889	**0.066**	**0.009**	0.149	0.633
	0.0 vs. 20.0	0.354	0.256	0.799	0.431	0.158	0.871	**0.000**	**0.032**	**0.043**	**0.042**	0.369	0.513	0.180	0.471	0.400	0.287	**0.083**	**0.004**	0.041	0.236
	0.0 vs. 25.0	0.554	0.315	0.865	0.910	0.804	0.628	**0.000**	**0.007**	**0.010**	**0.007**	0.857	0.600	0.699	0.718	1.000	0.963	**0.087**	**0.003**	0.116	0.272

Appendix C

Appendix C, Table 1. Grass and forb seedlings emerging at Dundurn in 1997 as affected by the combined effects of precipitation and seedbed treatments.

Date	Precipitation treatment	Seedbed treatment			
		Control	Clubmoss killed	Clubmoss removed	Mean
21 May		Seedling density (seedlings m^{-2})			
	Irrigated	72	10	16	32.7
	Reduced	35	8	4	15.7
	Control	42	15	5	20.7
	Mean	49.7a[1]	11.0b	8.3b	23.0
11 June					
	Irrigated	94	30	17	47.0
	Reduced	38	12	6	18.7
	Control	110	79	6	65.0
	Mean	80.7a	40.3b	9.7b	43.6
30 June					
	Irrigated	63	48	41	50.7a
	Reduced	5	5	0	3.3c
	Control	23	44	6	24.3b
	Mean	30.3	32.3	15.7	26.1
14 July					
	Irrigated	22	14	11	15.7a
	Reduced	5	1	0	2.0b
	Control	4	10	0	4.7b
	Mean	10.3	8.3	3.7	7.4
30 July					
	Irrigated	8	6	1	5.0a
	Reduced	0	0	0	0.0b
	Control	0	0	0	0.0b
	Mean	2.7	2.0	0.3	1.7
15 August					
	Irrigated	0	0	0	0.0
	Reduced	0	0	0	0.0
	Control	0	0	0	0.0
	Mean	0	0	0	0.0
30 August					
	Irrigated	16b	155a	224a	131.7
	Reduced	2b	0b	3b	1.7
	Control	10b	18b	213a	80.3
	Mean	9.3	57.7	146.7	71.2
15 September	Irrigated	18b	231a	150a	133.0
	Reduced	2b	5b	0b	2.3
	Control	16b	9b	145a	56.7
	Mean	12.0	81.7	98.3	64.0

[1] Within survey dates means followed by similar letters or with no letters within a column or row are not significantly different ($P \leq 0.05$).

Appendix C, Table 2. Grass and forb seedlings that survived from different dates of emergence at Dundurn in 1997 as affected by the combined effects of precipitation and seedbed treatments. Survival was determined on 30 August 1997.

Date	Precipitation treatment	--------------Seedbed treatment--------------			
		Control	Clubmoss killed	Clubmoss removed	Mean
21 May		------------Seedling density (seedlings m^{-2})------------			
	Irrigated	35	3	5	14.3
	Reduced	7	1	0	2.7
	Control	8	2	2	4.0
	Mean	16.7a[1]	2.0b	2.3b	7.0
11 June					
	Irrigated	40	7	9	18.7
	Reduced	5	1	0	2.0
	Control	32	12	0	14.7
	Mean	25.7a	6.7b	3.0b	11.8
30 June					
	Irrigated	25	8	8	13.7a
	Reduced	2	1	0	1.0b
	Control	6	10	1	5.7ab
	Mean	11.0	6.3	3.0	6.8
14 July					
	Irrigated	9	7	0	5.3a
	Reduced	1	1	0	0.7b
	Control	0	1	0	0.3b
	Mean	3.3a	3.0a	0.0b	2.1
30 July					
	Irrigated	2	1	0	1.0
	Reduced	0	0	0	0.0
	Control	0	0	0	0
	Mean	0.7	0.3	0.0	0.3
15 August					
	Irrigated	0	0	0	0.0
	Reduced	0	0	0	0.0
	Control	0	0	0	0.0
	Mean	0.0	0.0	0.0	0.0

[1] Within survey dates means followed by similar letters or with no letters within a column or row are not significantly different ($P \leq 0.05$).

Appendix C, Table 3. The number of grass seedlings emerging from different microsites at Dundurn in 1997.

Date	Microsite	Number of seedlings observed[a,b]	Number of seedlings greater than expected, less than expected, or proportional to availability of microsites[c]
21 May	Live clubmoss	**116**	>Expected
	Dead clubmoss	**308**	>Expected
	Bare soil	**68**	<Expected
	Litter	**64**	<Expected
	Total	**556**	
11 June	Live clubmoss	**264**	>Expected
	Dead clubmoss	**276**	Proportional to availability
	Bare soil	**116**	<Expected
	Litter	**260**	>Expected
	Total	**916**	
30 June	Live clubmoss	**156**	>Expected
	Dead clubmoss	**244**	>Expected
	Bare soil	**52**	<Expected
	Litter	**76**	<Expected
	Total	**528**	
14 July	Live clubmoss	**24**	Proportional to availability
	Dead clubmoss	**36**	Proportional to availability
	Bare soil	**8**	<Expected
	Litter	**72**	>Expected
	Total	**140**	
30 July	Live clubmoss	4	*
	Dead clubmoss	12	*
	Bare soil	8	*
	Litter	12	*
	Total	36	
15 August	Live clubmoss	0	–[d]
	Dead clubmoss	0	–
	Bare soil	0	–
	Litter	0	–
	Total	0	
30 August	Live clubmoss	0	*
	Dead clubmoss	4	*
	Bare soil	8	*
	Litter	4	*
	Total	16	
15 September	Live clubmoss	**12**	>Expected
	Dead clubmoss	**0**	<Expected
	Bare soil	**4**	Proportional to availability
	Litter	**8**	Proportional to availability
	Total	**24**	

[a] Proportion of total ground cover is 0.16 for live clubmoss, 0.29 for dead clubmoss, 0.32 for bare soil and 0.23 for litter. Values represent expected seedling observations if seedlings occurred in each microsite in exact proportion to availability.

[b] Within dates bold numbers indicate total number of observed seedlings emerging in microsites was significantly different than random at $X^2_{0.05,3} = 7.4$.

[c] >Expected, <Expected, and Proportional to availability of microsite types determined from Bonferroni Confidence Intervals ($P \leq 0.05$).

* Bonferroni test not conducted because X^2 was not significant ($P > 0.05$).

Appendix C, Table 4. The number of forb seedlings emerging from different microsites at Dundurn in 1997.

Date	Microsite	Number of seedlings observed[a,b]	Number of seedlings greater than expected, less than expected, or proportional to availability of microsites[c]
21 May	Live clubmoss	**12**	< Expected
	Dead clubmoss	**96**	>Expected
	Bare soil	**40**	<Expected
	Litter	**28**	<Expected
	Total	**176**	
11 June	Live clubmoss	**60**	Proportional to availability
	Dead clubmoss	**152**	>Expected
	Bare soil	**40**	<Expected
	Litter	**108**	>Expected
	Total	**360**	
30 June	Live clubmoss	**80**	>Expected
	Dead clubmoss	**68**	<Expected
	Bare soil	**120**	Proportional to availability
	Litter	**84**	Proportional to availability
	Total	**352**	
14 July	Live clubmoss	**16**	Proportional to availability
	Dead clubmoss	**52**	>Expected
	Bare soil	**20**	<Expected
	Litter	**16**	Proportional to availability
	Total	**104**	
30 July	Live clubmoss	0	*
	Dead clubmoss	8	*
	Bare soil	4	*
	Litter	4	*
	Total	16	
15 August	Live clubmoss	0	--[d]
	Dead clubmoss	0	--
	Bare soil	0	--
	Litter	0	--
	Total	0	
30 August	Live clubmoss	**264**	<Expected
	Dead clubmoss	**372**	<Expected
	Bare soil	**852**	>Expected
	Litter	**768**	>Expected
	Total	**2,256**	
15 September	Live clubmoss	**432**	Proportional to availability
	Dead clubmoss	**376**	<Expected
	Bare soil	**936**	>Expected
	Litter	**796**	>Expected
	Total	**2,540**	

[a] Proportion of total ground cover is 0.16 for live clubmoss, 0.29 for dead clubmoss, 0.32 for bare soil and 0.23 for litter. Values represent expected seedling observations if seedlings occurred in each microsite in exact proportion to availability.

[b] Within dates bold numbers indicate total number of observed seedlings emerging in microsites was significantly different than random at $X^2_{0.05,3} = 7.4$.

[c] >Expected, <Expected, and Proportional to availability of microsite types determined from Bonferroni Confidence Intervals ($P \leq 0.05$).

* Bonferroni test not conducted because X^2 was not significant ($P > 0.05$).

Appendix C, Table 5. Grass and forb seedlings emerging at Dundurn in 1998 as affected by the combined effects of precipitation and seedbed treatments.

Date	Precipitation treatment	Seedbed treatment			
		Control	Clubmoss killed	Clubmoss removed	Mean
		Seedling density (seedlings m^{-2})			
19 May					
	Irrigated	19	11	15	15.0a[1]
	Reduced	5	4	9	6.0b
	Control	0	6	8	4.7b
	Mean	8.0	7.0	10.7	8.6
17 June					
	Irrigated	3	11	10	8.0a
	Reduced	0	5	13	6.0b
	Control	0	0	1	0.3c
	Mean	1.0b	5.3a	8.0a	4.8
14 July					
	Irrigated	1	27	31	22.7a
	Reduced	3	3	15	7.0b
	Control	4	8	17	9.7b
	Mean	5.7	12.7	21.0	13.1
18 August					
	Irrigated	0	21	5	8.7
	Reduced	0	1	0	0.3
	Control	0	0	0	0.0
	Mean	0.0	7.3	1.7	3.0

[1] Within survey dates means followed by similar letters or with no letters within a column or row are not significantly different ($P \leq 0.05$).

Appendix C, Table 6. Grass and forb seedlings that survived from different dates of emergence at Dundurn in 1998 as affected by the combined effects of precipitation and seedbed treatments.

Date	Precipitation treatment	Seedbed treatment			
		Control	Clubmoss killed	Clubmoss removed	Mean
19 May		Seedling density (seedlings m^{-2})			
	Irrigated	6	1	3	3.3
	Reduced	1	2	2	1.7
	Control	0	2	1	1.0
	Mean	2.3	1.7	2.0	2.0
17 June					
	Irrigated	0c[1]	3ab	5a	2.7
	Reduced	0c	2bc	1bc	1.0
	Control	0c	0c	0c	0.0
	Mean	0.0	1.7	2.0	1.2
14 July					
	Irrigated	2	5	1	5.7a
	Reduced	1	0	4	1.7b
	Control	0	1	1	0.7b
	Mean	1.0b	2.0ab	5.0a	2.7
18 August					
	Irrigated	0	21	3	8.0
	Reduced	0	1	0	0.33
	Control	0	0	0	0.00
	Mean	0.0	7.3	1.0	2.

[1] Within survey dates means followed by similar letters or with no letters within a column or row are not significantly different ($P \leq 0.05$).

Appendix C, Table 7. The number of grass seedlings emerging in different microsites at Dundurn in 1998.

Date	Microsite	Number of seedlings observed[a,b]	Number of seedlings greater than expected, less than expected, or proportional to availability of microsites[c]
19 May	Live clubmoss	**36**	Proportional to availability
	Dead clubmoss	**36**	<Expected
	Bare soil	**80**	>Expected
	Litter	**36**	<Expected
	Total	**188**	
17 June	Live clubmoss	**4**	<Expected
	Dead clubmoss	**24**	<Expected
	Bare soil	**64**	>Expected
	Litter	**36**	Proportional to availability
	Total	**128**	
14 July	Live clubmoss	**16**	<Expected
	Dead clubmoss	**88**	Proportional to availability
	Bare soil	**176**	>Expected
	Litter	**28**	<Expected
	Total	**308**	
18 August	Live clubmoss	**0**	<Expected
	Dead clubmoss	**16**	Proportional to availability
	Bare soil	**36**	>Expected
	Litter	**12**	<Expected
	Total	**64**	

[a] Proportion of total ground cover is 0.20 for live clubmoss, 0.31 for dead clubmoss, 0.18 for bare soil and 0.25 for litter. Values represent expected seedling observations if seedlings occurred in each microsite in exact proportion to availability.

[b] Within dates bold numbers indicate total number of observed seedlings emerging in microsites was significantly different than random at $X^2_{0.05,3} = 7.4$.

[c] >Expected, <Expected, and Proportional to availability of microsite types determined from Bonferroni Confidence Intervals ($P \leq 0.05$).

* Bonferroni test not conducted because X^2 was not significant ($P > 0.05$).

Appendix C, Table 8. The number forb seedlings emerging from different microsites at Dundurn in 1998.

Date	Microsite	Number of seedlings observed[ab]	Number of seedlings greater than expected, less than expected, or proportional to availability of microsites[c]
19 May	Live clubmoss	0	<Expected
	Dead clubmoss	36	<Expected
	Bare soil	80	>Expected
	Litter	36	Proportional to availability
	Total	152	
17 June	Live clubmoss	44	Proportional to availability
	Dead clubmoss	24	<Expected
	Bare soil	64	>Expected
	Litter	36	Proportional to availability
	Total	168	
14 July	Live clubmoss	84	Proportional to availability
	Dead clubmoss	44	<Expected
	Bare soil	176	>Expected
	Litter	28	<Expected
	Total	332	
18 August	Live clubmoss	44	>Expected
	Dead clubmoss	16	<Expected
	Bare soil	36	>Expected
	Litter	12	<Expected
	Total	108	

[a] Proportion of total ground cover is 0.20 for live clubmoss, 0.31 for dead clubmoss, 0.18 for bare soil and 0.25 for litter. Values represent expected seedling observations if seedlings occurred in each microsite in exact proportion to availability.

[b] Within dates bold numbers indicate total number of observed seedlings emerging in microsites was significantly different than random at $X^2_{0.05,3} = 7.4$.

[c] >Expected, <Expected, and Proportional to availability of microsite types determined from Bonferroni Confidence Intervals ($P \leq 0.05$).

* Bonferroni test not conducted because X^2 was not significant ($P > 0.05$).

Appendix C, Table 9. Grass and forb seedlings emerging Rudy in 1998 as affected by the combined effects of precipitation and seedbed treatments.

Date	Precipitation treatment	-------------Seedbed treatment-------------			
		Control	Clubmoss killed	Clubmoss Removed	Mean
11 May		-------Seedling density (seedlings m^{-2})-----------			
	Irrigated	5	0	0	1.7
	Reduced	5	4	0	3.0
	Control	1	1	0	0.7
	Mean	3.7a[1]	1.7ab	0.0b	1.8
26 May					
	Irrigated	1	2	0	1.0
	Reduced	0	0	0	0.0
	Control	0	2	0	0.7
	Mean	0.3ab	1.3a	0.0b	0.6
8 June					
	Irrigated	3	1	2	2.0
	Reduced	0	0	0	0.0
	Control	1	1	0	0.7
	Mean	1.3	0.7	0.7	0.9
23 June					
	Irrigated	0c	5bc	37a	14.0
	Reduced	0c	1c	0c	0.3
	Control	1c	2c	8b	3.7
	Mean	0.3	2.7	15.0	6.0
7 July					
	Irrigated	16b	42b	182a	80.0
	Reduced	6b	3b	11b	6.7
	Control	2b	25b	103a	43.3
	Mean	8.0	23.3	98.7	43.3
22 July					
	Irrigated	19	4	13	12.0a
	Reduced	2	0	0	0.b
	Control	1	0	2	1.0b
	Mean	7.3	1.3	5.0	4.6
11 August					
	Irrigated	1	0	1	0.7
	Reduced	0	0	0	0.0
	Control	0	0	0	0.0
	Mean	0.3	0.0	0.3	0.2
24 August					
	Irrigated	0	3	3	2.0
	Reduced	0	0	0	0.0
	Control	1	0	1	0.7
	Mean	0.3	1.0	1.3	0.9

[1] Within survey dates means followed by similar letters or with no letters within a column or row are not significantly different ($P \leq 0.05$).

Appendix C, Table 10. Grass and forb seedlings that survived on different dates at Rudy in 1998 as affected by the combined effects of precipitation and seedbed treatments.

Date	Precipitation Treatment	Seedbed treatment			
		Control	Clubmoss killed	Clubmoss Removed	Mean
		Seedling density (seedlings m^{-2})			
11 May	Irrigated	0[1]	0	0	0.0
	Reduced	0	0	0	0.0
	Control	0	0	0	0.0
	Mean	0.0	0.0	0.0	0.0
26 May	Irrigated	0	0	0	0.0
	Reduced	0	0	0	0.0
	Control	0	0	0	0.0
	Mean	0.0	0.0	0.0	0.0
8 June	Irrigated	0	1	0	0.3
	Reduced	0	0	0	0.0
	Control	0	0	0	0.0
	Mean	0.0	0.3	0.0	0.1
23 June	Irrigated	0	0	0	0.0
	Reduced	0	0	0	0.0
	Control	0	0	0	0.0
	Mean	0.0	0.0	0.0	0.0
7 July	Irrigated	0	0	3	1.0
	Reduced	0	0	1	0.3
	Control	0	1	0	0.3
	Mean	0.0	0.3	1.3	0.6
22 July	Irrigated	0	0	0	0.0
	Reduced	1	0	0	0.3
	Control	0	0	0	0.0
	Mean	0.3	0.0	0.0	0.1
11 August	Irrigated	1	0	0	0.3
	Reduced	0	0	0	0.0
	Control	0	0	0	0.0
	Mean	0.3	0.0	0.0	0.1
24 August	Irrigated	0	1	2	1.0
	Reduced	0	0	0	0.0
	Control	1	0	0	0.3
	Mean	0.3	0.3	0.7	0.4

[1] Within survey dates means followed by similar letters or with no letters within a column or row are not significantly different ($P \leq 0.05$).

Appendix C, Table 11. The number of grass seedlings emerging from different microsites at Rudy in 1998.

Date	Microsite	Number of seedlings observed[a][b]	Number of seedlings greater than expected, less than expected, or proportional to availability of microsites[c]
11 May	Live clubmoss	**0**	< Expected
	Dead clubmoss	**8**	> Expected
	Bare soil	**0**	< Expected
	Litter	**4**	Proportional to availability
	Total	**12**	
26 May	Live clubmoss	**0**	< Expected
	Dead clubmoss	**0**	< Expected
	Bare soil	**8**	> Expected
	Litter	**0**	< Expected
	Total	**8**	
8 June	Live clubmoss	**0**	< Expected
	Dead clubmoss	**4**	Proportional to availability
	Bare soil	**4**	Proportional to availability
	Litter	**0**	< Expected
	Total	**8**	
23 June	Live clubmoss	**0**	< Expected
	Dead clubmoss	**8**	> Expected
	Bare soil	**0**	< Expected
	Litter	**0**	< Expected
	Total	**8**	
7 July	Live clubmoss	**4**	< Expected
	Dead clubmoss	**52**	> Expected
	Bare soil	**28**	Proportional to availability
	Litter	**0**	< Expected
	Total	**84**	
22 July	Live clubmoss	**0**	< Expected
	Dead clubmoss	**12**	Proportional to availability
	Bare soil	**16**	> Expected
	Litter	**4**	< Expected
	Total	**32**	
11 August	Live clubmoss	0	___[d]
	Dead clubmoss	0	___[d]
	Bare soil	0	___[d]
	Litter	0	___[d]
	Total	0	
24 August	Live clubmoss	**0**	< Expected
	Dead clubmoss	**4**	Proportional to availability
	Bare soil	**8**	> Expected
	Litter	**0**	< Expected
	Total	**12**	

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[a] Proportion of total ground cover is 0.19 for live clubmoss, 0.25 for dead clubmoss, 0.24 for bare soil and 0.27 for litter. Values represent expected seedling observations if seedlings occurred in each microsite in exact proportion to availability.

[b] Within dates bold numbers indicate total number of observed seedlings emerging in microsites was significantly different than random at $X^2_{0.05,3} = 7.4$.

[c] > Expected, < Expected, and Proportional to availability of microsite types determined from Bonferroni Confidence Intervals ($P \leq 0.05$).

[d] Bonferroni test not conducted because X^2 was not significant ($P > 0.05$).

Appendix C, Table 12. The number of forb seedlings emerging from different microsites at Rudy in 1998.

Date	Microsite type	Number of seedlings observed[ab]	Number of seedlings greater than expected, less than expected, or proportional to availability of microsites[c]
11 May	Live clubmoss	**20**	Proportional to availability
	Dead clubmoss	**8**	<Expected
	Bare soil	**20**	Proportional to availability
	Litter	**12**	Proportional to availability
	Total	**60**	
26 May	Live clubmoss	0	*
	Dead clubmoss	0	*
	Bare soil	4	*
	Litter	0	*
	Total	4	
8 June	Live clubmoss	**0**	<Expected
	Dead clubmoss	**4**	Proportional to availability
	Bare soil	**16**	>Expected
	Litter	**8**	Proportional to availability
	Total	**28**	
23 June	Live clubmoss	**8**	<Expected
	Dead clubmoss	**8**	<Expected
	Bare soil	**188**	>Expected
	Litter	**12**	<Expected
	Total	**216**	
7 July	Live clubmoss	**108**	<Expected
	Dead clubmoss	**52**	<Expected
	Bare soil	**1,136**	>Expected
	Litter	**216**	<Expected
	Total	**1,512**	
22 July	Live clubmoss	**52**	>Expected
	Dead clubmoss	**12**	<Expected
	Bare soil	**60**	>Expected
	Litter	**16**	<Expected
	Total	**140**	
11 August	Live clubmoss	0	*
	Dead clubmoss	0	*
	Bare soil	4	*
	Litter	0	*
	Total	4	
24 August	Live clubmoss	**0**	<Expected
	Dead clubmoss	**4**	Proportional to availability
	Bare soil	**16**	>Expected
	Litter	**4**	Proportional to availability
	Total	**24**	

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[a] Proportion of total ground cover is 0.19 for live clubmoss, 0.25 for dead clubmoss, 0.24 for bare soil and 0.27 for litter. Values represent expected seedling observations if seedlings occurred in each microsite in exact proportion to availability.

[b] Within dates bold numbers indicate total number of observed seedlings emerging in microsites was significantly different than random at $X^2_{0.05,3} = 7.4$.

[c] >Expected, <Expected, and Proportional to availability of microsite types determined from Bonferroni Confidence Intervals ($P \leq 0.05$).

* Bonferroni test not conducted because X^2 was not significant ($P > 0.05$).